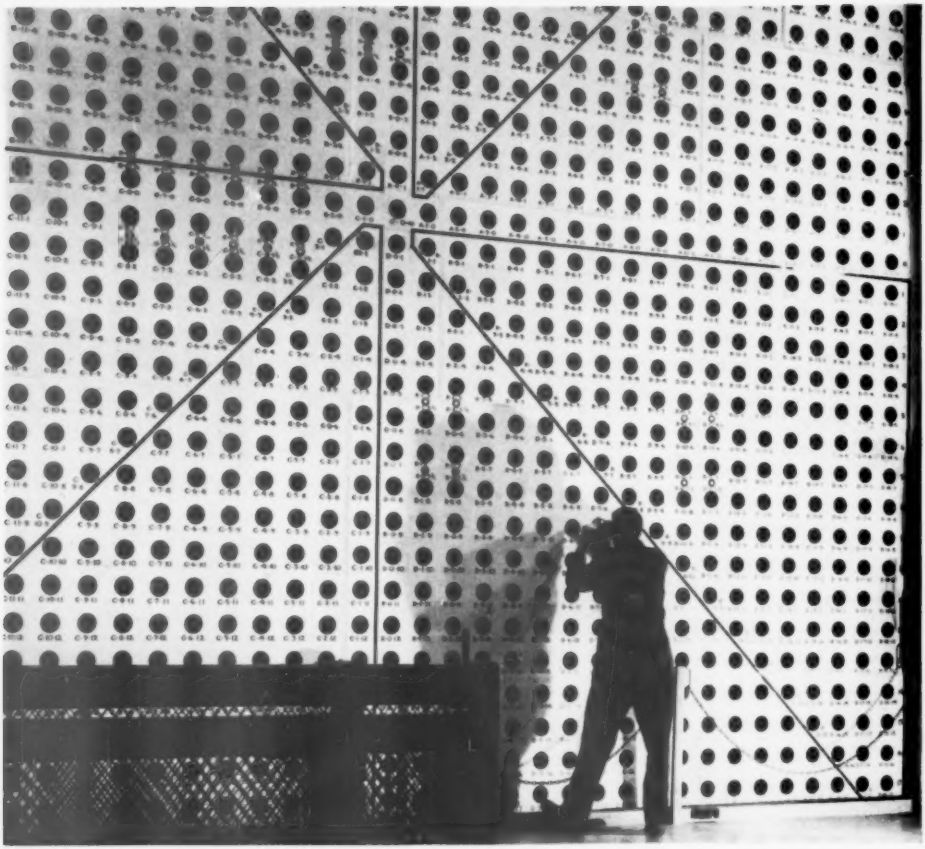
NUCLEONICS



Technician standing on elevator platform uses periscope to observe position of uranium slug in a fuel channel of the Brookhaven National Laboratory reactor. Holes on eight-inch centers that pierce the five-foot-thick concrete south face are used to load reactor

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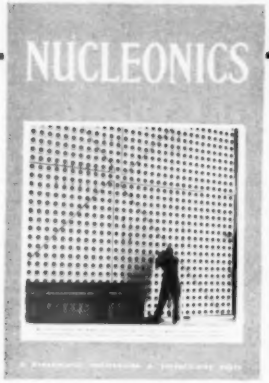

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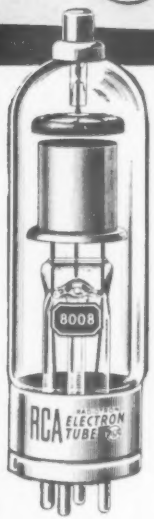

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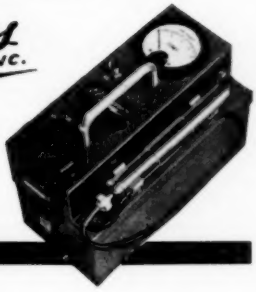
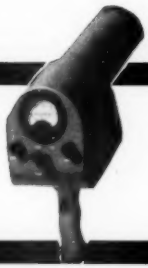


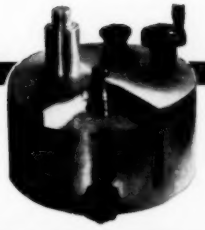
SM-3 PORTABLE SURVEY INSTRUMENT

Small, rugged compact portable survey instrument has direct-reading large 3 inch meter with 3 full scale ranges of .2, 2.0, and 20 MR/HR. Measures both beta and gamma radiation with extreme accuracy. Free easy access to batteries, complete weatherproof construction, and unusually long battery life make this light 8½ lb. instrument an excellent choice for outdoor field work or laboratory use. Write for Bulletin.



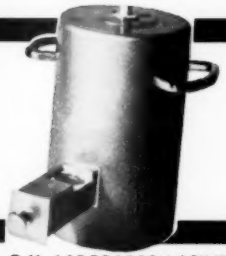
CP-3 "CUTIE-PIE"

Compact portable "Cutie Pie" is extremely sensitive to both beta and gamma radiation. Three full scale ranges of 25, 250, and 2500 MR/HR are read directly on large three inch meter. Can also be had in ranges of 50, 500, 5000 MR/HR and 100, 1000, and 10,000 MR/HR. This unusually accurate instrument has been designed for ease of operation. Free access to batteries and tubes is provided, as well as a sliding top cover that exposes entire circuit for fast service. Weight less than 4 pounds. A fine hand instrument for laboratory or field use. Write for Bulletin.



FGG 3 PREFLUSH FLOW GAS COUNTER

This new preflush gas counter for alpha and weak beta radiation designed characteristics to speed work and increase reliability of results. The gear driven platform is readily rotated by control knob. An elevator sample platform positions sample readily by a second control knob. Load, preflush, and count positions are possible with the rotating sample holder. Preflush position has separate gas entrance, exit, and bubbler to prevent contamination backup from test chamber. A completely self-contained unit of brass construction, heavily chrome plated. Write for Bulletin.



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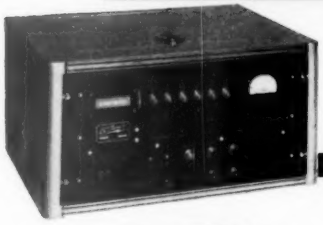
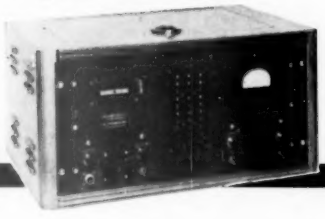
More accurate readings through lowered background count make this shielded sample test changer unusually reliable. Two inches of lead shielding on all sides of the sample is provided. An additional two inches of lead at front and back of sample drawer cause sample to be completely enclosed when sample is placed. Because GM tubes are readily accessible from top, quick changes are possible. The sample drawer is provided with removable shelves so that speedy sample changes are possible. Samples may be placed on planchettes or filter paper rings. The inner shell is made of ⅛" aluminum tubing to minimize scattering. Write for Bulletin.



LS 64 SS G.M. LABORATORY SCINTILLATION SCALER

This extremely accurate Geiger-Müller laboratory scintillation scaler offers precise measurements of radiation intensities. Employs the reliable Higinbotham scaling circuit with a built-in impulse register. Six controls include power switch, high voltage, Count-Stop-Reset Switch, and adjustments for high voltage, and impulse register reset. Scaling ratios at 4, 8, 32, or 64. Sixteen automatic shut-off points are incorporated in this instrument. Terminations are provided for oscilloscope, synchronous clock, and pre-set timer. The instrument is mounted in rack type cabinet. Write for Bulletin.



LS 1000 A LABORATORY SCALER

Decimal decade type laboratory scaler uses reliable Higinbotham circuit operating a built-in impulse register. All transformers are hermetically sealed for long life, and all high voltage capacitors are oil filled. Counts up to one billion before recycling. Direct reading. The light cluster is arranged for easy reading and close association with the impulse register. Counts up to 10,000 evenly spaced pulses per second. Terminations for other instruments, such as pre amplifier and running time meter, make this a reliable, versatile instrument for accurate laboratory counting. Write for Bulletin.

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°F	°C
7040	3893
7030	3888
7020	3882
7010	3877
7000	3871
6990	3866
6980	3860
6970	3854
6960	3849
6950	3843
6940	3838

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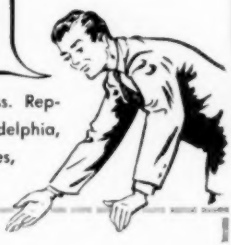

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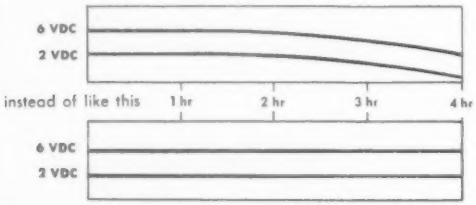

Haven't you been plagued by input voltage drop, particularly in the course of long-running experiments? Or have you had to interrupt or defer work while batteries were being charged or replaced?

The Sorensen Model E-6/2-5 Nobatron* has been specifically designed to exclude this difficulty. Using it, you can be sure your equipment is getting 2 and 6 volts DC, **plus or minus 0.01%**, with that accuracy maintained indefinitely at normal room temperature.

Furthermore, circuitry developed for the Model E-6/2-5 Nobatron is advanced in simplicity, involving no moving parts. That means easy maintenance, trouble-free operation.

Write for information.

SPECIFICATIONS

Input voltage range	95-130VAC, 1φ, 50-60 cycles
Output	
#1 for lamp	6VDC adjustable ±10% at 5 amperes
#2 for filament	6VDC at 100 Ma.
#3 for bias	2VDC adjustable ±10% at 100 Ma.
Filtering	
#1	1% max.
#2 & 3	0.05% max.
Regulation accuracy	±0.01% against line changes
Time constant	0.1 seconds under most severe line changes
Size:	17 x 12¼ x 17 self contained 19 x 12¼ panel for relay rack mounting
Weight:	Approximately 90 pounds
Meters:	No meters are provided due to the extreme regulation accuracy involved.

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hermetically sealed running time meter

REGISTERS OPERATING TIME OF MACHINE TOOLS, ELECTRONIC, ELECTRICAL OR GENERAL INDUSTRIAL EQUIPMENT

SPECIFICATIONS

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- Drawn steel case provides magnetic shielding
- Self-starting synchronous motor
- Moderately priced

Marion's new Running Time Meter is absolutely tamper-proof because it is sealed in a drawn steel case. Designed for a wide range of operating temperatures, it is also ideal for use in hazardous atmospheres. The easy-to-read dial is viewed through tempered glass crystal which is fused directly to the case.

Powered by a durable self-starting synchronous motor, available for 110-125, 220-250 volts . . . 50 or 60 cycle A. C. . . . the Marion Running Time Meter occupies no more panel space than an ordinary 3½" meter.

Demands of our national mobilization program come first, of course, but we will gladly supply further information and serve you to the best of our ability.

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RADIATION
INSTRUMENT
NEWS

New G-E Scintillation Counter . . .

Measures α, β, γ Radiation—Thermal Neutrons Too!

Vertical chimney containing 5819 photomultiplier tube lifts off for quick change of phosphors.

Four Easily Interchanged Phosphors Are Highly Efficient Detectors

By means of a special G-E phosphor, thermal neutrons can be measured with 25% efficiency with the new G-E Universal Scintillation Counter. Here also is alpha counting with low background of one or two counts per hour. Plateau length for thin alpha sources is 150 volts; plateau slope for beta counting is of the order of 1.2.

The laboratory technician pictured above is placing a sample smear in the large 2-inch diameter sample chamber, which is then slid under the vertical tube containing phosphor and 5819 photomultiplier tube. Phosphors supplied for detecting are as follows: alpha—zinc sulphide, beta—anthracene, gamma—sodium iodide. Scintillations can be counted on any standard scaler.

A portable model of the Scintillation Counter is available.

For an illustrated bulletin on these and other G-E Radiation Instruments, write for GEA-5735 to: General Electric Company, Section 687-87, Schenectady 5, N. Y.

GENERAL ELECTRIC

687-87

NUCLEONICS

MARCH, 1952

A Study in Contrasts

Two conferences in Washington the last week in January were at opposite poles. One was at the Shoreham Hotel, the other at Atomic Energy Commission headquarters. At one, the information flowed freely; at the other, it hardly flowed at all.

The first conference was a two-day symposium on scintillation counters at the Shoreham. Almost five hundred scientists and engineers came together to exchange their latest results and ideas on an instrument which has become an extremely important research tool in the past five years.

This tool has had lots of quirks and problems connected with it. Independent of one another, research workers in all parts of the country have tackled various aspects of the problem. The meeting at the Shoreham provided a forum for them to thrash out their ideas. Although most of the participants were connected with atomic energy work in one way or another, the discussions were completely unclassified. Time was the only limitation. Everyone benefited from this free and open meeting.

The second conference, the one held at AEC, was not by any means a scientific meeting. It was a press conference held in conjunction with the release of the Eleventh Semiannual Report to Congress of the Atomic Energy Commission. These reports, required by law, are intended to give Congress a picture of how this country's money is being spent in our vast atomic energy enterprise.

The press conferences are the one medium through which the general public can get its running picture of the goings-on behind the secrecy barriers. Here the press can confront the AEC commissioners and members of the commission staff with questions on what's happening in the atomic energy program and on the implications of such things in the lives of our citizenry.

Perhaps this is too idealized a picture. Experience certainly bears this out. The press is not learning about what makes our atomic energy program tick. And neither is the public. Instead their pipes are being filled with dreams about "fantastic" weapons and the like.

At this last conference, one reporter asked Chairman Dean, "Can you define what a fantastic weapon is?" Another asked, "Are there any *major* developments in the report at this time that have not been mentioned in releases or previous discussions that we have had here?" This question led Mr. Dean to ask one of the commission staff to suggest a few "leads" for the reporters.

And still another reporter said questioningly in commenting on the financial statement included in the report that, "It looks like there ought to be something significant in that."

The picture we get from this is that there is something wrong somewhere—either with the press or with the AEC. Our answer is that there is something wrong with both. The press doesn't know what questions to ask, and when questions are asked, the commissioners frequently can't answer them for reasons of security.

Thus we are lacking the interchange which is necessary to develop an enlightened public examination of the atomic energy program.

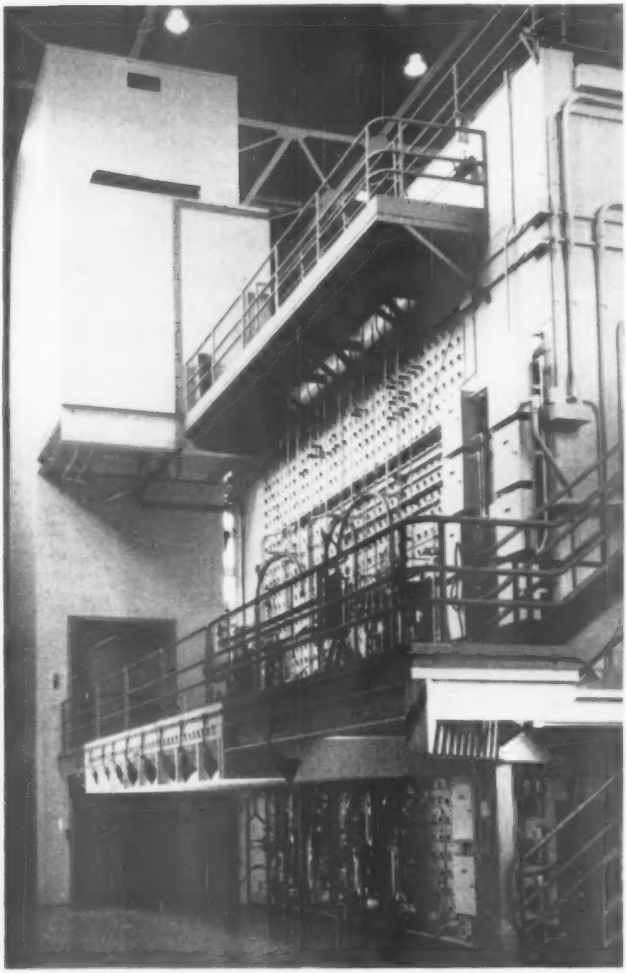
One way to tackle this problem would be to extend the commission's program of educating reporters. A far more fruitful idea, however, would be to lower some of the secrecy barriers. At the press conference, Mr. Dean said that no new significant areas of declassification are being considered. This is surprising, especially when one considers the growing industrial interest in this field and the need which AEC may soon have to attract even more industry.

The road to progress is via the "open forum," where we can all see what our problems are and can develop an interest in attacking them.

—*J.D.L.*

Nuclear Reactor Catalog

This is the first concise tabulation of declassified details of reactors already in operation and those in advanced stages of design and construction



NORTH FACE of the Brookhaven reactor shows the pneumatic-tube system used for moving containers of materials in and out of the reactor for irradiation. Deliveries can be made either to this face of the reactor or to one of several adjoining laboratories. Tall column at left houses freight elevator

By H. S. ISBIN
University of Minnesota
Minneapolis, Minnesota

FOLLOWING THE FIRST successful pile operation on December 2, 1942, the development of nuclear reactors has expanded to the point where now more than 25 reactors have been built and operated. Currently, there are more than 10 reactors reported to be in advanced stages of design and/or construction, with probably at least an additional half dozen in initial planning stages.

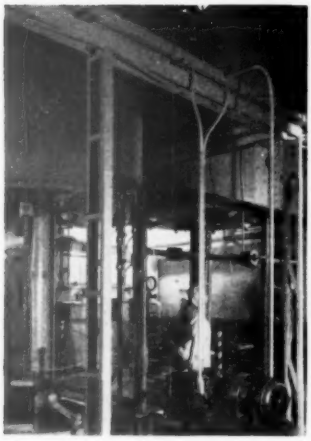
The purpose of this paper is to present a summary of the features of these reactors based upon the reports in the open literature. It is to be recognized that the nuclear reactor information made available to the public is based upon the following divisions for declassification of information (*1, 2*):

1. Research reactors of low power (information is completely declassifiable).

2. Higher power research reactors (some features are declassifiable).

3. Reactors having military significance (only a minimum of information is declassifiable).

These classifications are applied to United States, United Kingdom and Canadian reactors. Thus, for example, the United States Atomic Energy Commission has released excellent descriptions of the design, construction, and operation of the water-boilers, but



WEIGHTED CYLINDERS held at the top of shaft by solenoid are safety device for Oak Ridge reactor. If power fails, cylinders fall and develop pressure which plunges control rods into shut-down position

CHAIN REACTION in Oak Ridge reactor is being halted by operator at control console. He is throwing switch that will halt chain reaction by driving boron-steel control rods into the heart of the reactor. Shutdowns occur at least weekly for withdrawal of radioisotopes, insertion of new material to be irradiated, for maintenance work, and occasionally for the insertion of a number of fresh uranium fuel slugs

no significant details have been released for the submarine reactor.

The first assembly of materials that was used to produce a successfully controlled neutron chain reaction was in the form of a graphite-uranium pile; hence, the term "pile" was interpreted to signify a controlled, self-sustaining nuclear chain assembly. In later developments, most of the assemblies bear no resemblance to piles so that the expression nuclear reactor is to be preferred (*3*). Some British writers make the distinction that piles imply the use of natural uranium, and reactors, the use of enriched uranium, U^{233}, Pu^{239}, or U^{235} (*4*).

There is, however, a significant difference to be noted between "critical assemblies" and "exponential piles." These structures, or mock-ups, have been used to evaluate the feasibility of reactor designs.

An assembly composed of fuel, moderator, and other reactor components is termed critical when conditions for a controlled, self-sustaining neutron chain reaction have been fulfilled. For each new major reactor development, one would expect that a zero or very low-power mock-up would be built as a pilot. Critical assemblies properly are called reactors; CP-1, Zeep, Gleep, and Lopo have been declassified, but others such as the

(*Text continued on page 16*)

Reactors to Be Built in Other Countries

France

First stage of French program was the design, construction and operation of ZOE. The second stage is reported to include the construction of one or two reactors of medium power (about 15 kw) (*20, 35*).

India

An agreement has been signed between the Indian and French governments for cooperation in the construction of an atomic pile in southern India. Two other foreign governments are expected to cooperate (*36*).

Brazil

A pilot atomic power plant is to be erected in Minas Geraes State (*37*).

Canada

Approval has been given for a $30-million reactor of the NRX type. The moderator is to be heavy water (*40*).

Argentina

Reports have been made of the development of an atomic energy pilot plant and the construction of a thermonuclear reactor on Huemul Island (*41*). (Report viewed with considerable skepticism.)

Sweden

A 100-kw reactor is being built near Stockholm, and is expected to be finished in 1953. It will contain 3 to 4 tons of uranium, moderated by heavy water. Plans are to use it for research and isotope production.

Belgium

Plans for a reactor to be built in Belgium have been announced.

Holland

A reactor is planned to provide power for a 5,000-ton ship (*42*).

Available Data on Nuclear Reactors

Name	*Classification*	*Fuel*	*Fuel core*	*Reflector*
Reactors in Operation				
CP-1, Uranium-Graphite Pile (West Stands, Chicago) *(7, 8)*	Thermal Heterogeneous Graphite Research 200 watts	Uranium		
CP-2 (Palos Park, Chicago) *(8)*	Thermal Heterogeneous Graphite Research 200 watts	3,200 uranium metal lumps, $2\frac{1}{4}$ in. dia.; 14,500 uranium oxide lumps, $2\frac{1}{4}$ in. dia.; about 50 tons uranium; lumps spaced on $8\frac{1}{4}$-in. square lattice	About a 17-ft cube	12 in. graphite
GLEEP, Graphite Low-Energy Experimental Pile (Harwell, Eng.) *(9, 10)*	Thermal Heterogeneous Graphite Research 100 kw 3×10^{10}	12 tons of uranium bars, 0.9 in. dia, 12 in. long, sprayed with 0.003 in. Al; 21 tons of uranium oxide in Al cans 1.6 in. dia., 2 in. long; line lattice with $7\frac{1}{4}$-in. pitch	Cylindrical core 5.24 m long, 2.86 m radius; metal in central portions up to $1\frac{3}{4}$ m radius	Graphite in shape of an octagon
Oak Ridge (Oak Ridge National Laboratory, Oak Ridge, Tenn.) *(5, 11, 44)*	Thermal Heterogeneous Graphite Research 1,000 kw 10^{12}	Al-jacketed uranium slugs, 1.1 in. dia., 4 in. long, 2.57 lb per slug; 39–54 slugs per channel; 1,248 fuel channels on 8-in. rectangular lattice; diamond-shaped channel, $1\frac{3}{4}$ in. square	24-ft cube, including reflector	Graphite
Brookhaven (Brookhaven National Laboratory, Upton, N. Y.) *(12, 13, 43)*	Thermal Heterogeneous Graphite Research 28 Mw 4×10^{12}	Aluminum-clad uranium metal rods placed on 8-in. centers, both horizontally and vertically	Graphite moderator in two right rectangular prisms $12\frac{1}{2} \times 25 \times 25$ ft, separated by vertical openings for cooling air	
BEPO, British Experimental Pile (Harwell, Eng.) *(14, 15)*	Thermal Heterogeneous Graphite Research 4 Mw 10^{12}	0.9-in.-dia, 12-in.-long uranium bars, encased in Al; 28 tons for criticality, 40 tons for full load, central 900 channels used; 20 bars per channel, $7\frac{1}{4}$ in. between channels	Right cylinder, 10 ft radius, 20 ft long	About 3 ft of graphite
Hanford (Hanford, Wash.) *(11, 16)*	Thermal Heterogeneous Graphite Pu production ~1,000 Mw	Uranium		
Sellafield (Sellafield, Eng.) *(17)*	Pu production			
CP-3 (Argonne National Laboratory, Chicago) *(8)*	Thermal Heterogeneous Heavy water Research 300 kw 10^{12}	120 uranium metal rods 1.1 in. dia., 6 ft long; 3 tons of metal; square lattice, $5\frac{3}{8}$ in. centerline to centerline	$6\frac{1}{2}$ tons of heavy water moderator in a 72-in.-dia., 105-in.-high aluminum tank	2 ft of graphite
ZEEP (Chalk River, Canada) *(18, 19)*	Thermal Heterogeneous Heavy water Research 3.5 watts 5.7×10^{13}	Uranium rods stacked in aluminum tubes	10 tons of heavy water in steel tank, $6\frac{3}{4}$ ft dia., $8\frac{1}{2}$ ft high	Graphite

Shielding	*Over-all size*	*Control*	*Coolant*	*Remarks*	*Name*
				World's first reactor. Operated Dec. 2, 1942. After initial operation was dismantled to form basis for CP-2	**CP-1,** Uranium-Graphite Pile (West Stands, Chicago) *(7, 8)*
5-ft concrete walls; 6 in. lead and 4 ft wood on top	30 ft wide, 32 ft long, 21 ft high; 472 tons graphite; 1,400 tons total	Bronze strips covered with Cd. 1 regulating, 1 shim, and 3 safety	None		**CP-2,** (Palos Park, Chicago) *(8)*
Cubical concrete shield with walls about 5 ft thick	Large cube containing 505 tons graphite	Rods containing Cd. 4 coarse control, 1 fine control, and 6 safety	Air, at least 5,000 ft^3/min at subatmospheric pressure; maximum uranium cartridge temperature, 60° C		**GLEEP,** Graphite Low-Energy Experimental Pile (Harwell, Eng.) *(9, 10)*
Concrete, 7 ft thick	47 ft long, 38 ft wide, 32 ft high		Air, 100,000 ft^3/min drawn through reactor; fuel below 245° C; average moderator temperature 130° C	Used for isotope production. 1,000 kw is design power, operation has reached 3,800 kw	**Oak Ridge** (Oak Ridge National Laboratory, Oak Ridge, Tenn.) *(5, 11, 44)*
Concrete, 9 to 18 in. of steel; total 5 ft	38 × 55 ft; 20,000 tons, including foundation	Horizontal rods containing boron. Rods enter from two adjacent corners in two arrays of 8 rods each	Air, 300,000 ft^3/min at subatmospheric pressure. Each half of moderator complex cooled separately.	Temperature ranges from 125° to 175° C at experimental openings	**Brookhaven** (Brookhaven National Laboratory, Upton, N. Y.) *(12, 13, 43)*
6-in. cast iron plate, and 6-ft concrete on sides and 7½ in. on top; 600 tons steel, 3,000 tons concrete		4 horizontal and 10 vertical boron-carbide filled hollow steel rods, 2 in. dia.	Air; single pass, 180,000 ft^3/min. Cross-section of each empty channel is 3½ in^2.	Maximum surface temperature 200° C. A hot-water system to recover heat is being installed *(30)*	**BEPO,** British Experimental Pile (Harwell, Eng.) *(14, 15)*
			Water	Power information is classified. Three units in operation in 1945, and additional reactors have been built	**Hanford** (Hanford, Wash.) *(11, 16)*
				Two reactors are reported in operation	**Sellafield** (Sellafield, Eng.) *(17)*
4 in. Pb-Cd, and 8-ft octagonal concrete wall 13 ft high; top shield contains Cd, 1 ft lead, and 4 ft wood and steel		Rods containing Cd metal; 2 control, 3 shim, and 2 safety	200 gal/min heavy water	Helium is circulated through reactor to sweep out dissociated heavy water, and to prevent influx of air containing ordinary water	**CP-3** (Argonne National Laboratory, Chicago) *(8)*
Water tanks, 3 ft thick		4 plates, 8 rods, cadmium-coated stainless steel	None	Maximum power is 30 watts	**ZEEP** (Chalk River, Canada) *(18, 19)*

Continued

Reactors in Operation (Continued)

Name	*Classification*	*Fuel*	*Fuel core*	*Reflector*
ZOE (Chatillon, France) *(20)*	Thermal Heterogeneous Heavy water Research 10 kw	Sintered uranium oxide compressed to bars of density 8.4, contained in aluminum holders; about 30 tons	Cylindrical aluminum vat containing about 6,000 liters heavy water	Graphite
JEEP (Kjeller, Norway) *(21)*	Thermal Heterogeneous Heavy water Research 100 kw $>3 \times 10^{13}$	2,200-kg uranium slugs in Al tubes; 35.5 kg per rod; rods 25.4 mm dia, 300 mm long, placed on 180-mm centers	1.9 m long; 7 tons of heavy water moderator in 2-m.-dia. tank	Graphite 700 mm thick
NRX (Chalk River, Canada) *(22, 23)*	Thermal Heterogeneous Heavy water Research 10 Mw 5.8×10^{13}	176 uranium rods	Heavy-water moderator contained in cylindrical vessel, 10 ft high, 8 ft dia.	Graphite
LOPO Low Power Water Boiler (Los Alamos, New Mexico) *(24, 25)*	Thermal Homogeneous Light water Research $\frac{1}{20}$ watt	Enriched uranium sulfate solution containing 580 gm U^{235}, 3,378 gm U^{238}, 534 gm S, 14,068 gm O, 1,573 gm H; density at 39° C is 1.348 gm/cm³	Uranyl sulfate solution in 15-liter stainless-steel sphere, $\frac{1}{32}$ in. thick, 1 ft dia.	3 × 3 × 6-in. bricks of BeO, ρ = 2.7; graphite on bottom
HYPO, High Power Water Boiler (Los Alamos, New Mexico) *(8, 25)*	Thermal Homogeneous Light water Research 6 kw 3×10^{13}	Enriched uranium nitrate solution containing 869.6 gm U^{235}, 5,341 gm U^{238}, 731 gm N, 13,780 gm O, 1,312 gm H	13.65 liters of $UO_2(NO_3)_2 6H_2O$ in H_2O, ρ = 1.615, in stainless-steel sphere $\frac{1}{16}$ in. thick, 12 in. dia.	24 × 24 × 27-in. BeO surrounded by graphite to form a 60 × 48 × 60-in. rectangular parallelepiped
Los Alamos Fast Reactor (Los Alamos, New Mexico *(3, 16, 26, 27)*	Fast Heterogeneous Research 10 kw 5×10^{12}	Rods of pure plutonium metal		
EBR, Experimental Breeder Reactor (Reactor Testing Station, Arco, Idaho) *(16, 28)*	Fast Heterogeneous Research Breeding	U^{235}		
PPA, Preliminary Pile Assembly (Knolls Atomic Power Laboratory, Schenectady, N. Y.) *(38)*				
Russian reactors *(39)*				

Reactors in Advanced Stages of Design or Construction

Low-Cost Low-Power (North American Aviation, Inc., Downey, Calif.) *(29, 30)*	Thermal Heterogeneous Graphite Research 160–200 kw 10^{12}	Enriched uranium	Hexagonal prism $4\frac{1}{2}$ ft dia. $4\frac{1}{2}$ ft high. Graphite and uranium in gas-tight aluminum tank	30 in. of graphite
Raleigh (North Carolina State College, Raleigh, N. C.) *(32-34)*	Thermal Homogeneous Light water Research 10 kw $>10^{12}$	Light water solution of UO_2SO_4 enriched with 915 gm U^{235}	Reactor solution contained in stainless-steel cylinder $\frac{1}{16}$ in. thick, 11 in. high, $10\frac{3}{4}$ in. dia.	16 in. graphite

Shielding	*Over-all size*	*Control*	*Coolant*	*Remarks*	*Name*
Concrete walls 1.5 m thick	5-m cube	Cadmium plates	Heavy water		**ZOE** (Chatillon; France) (*20*)
Octagonal concrete shield, 2 m thick on sides		4 cadmium plates 1,300 mm long, 350 mm wide, 1.7 mm thick, held between Al plates	4 liters of heavy water per sec (inlet 20° C, outlet 40° C)		**JEEP** (Kjeller, Norway) (*21*)
8 ft concrete	34 ft dia., 34 ft high	Varying D_2O level, cadmium and boron rods	Water		**NRX** (Chalk River, Canada) (*22, 23*)
		Cadmium cylinder, $\frac{3}{4}$ in. dia., 34 in. long	Water. Maximum temperature is 39° C		**LOPO**, Low-Power Water Boiler (Los Alamos, New Mexico) (*24, 25*)
4 in. lead, $\frac{1}{32}$ in. cadmium, 5 ft concrete		Rods containing cadmium, 1 shim, 2 control, 1 safety	50 gal/hr water through 6-turn, $\frac{1}{2}$-in., i.d., 157-in.-long coil. Maximum solution temperature 185° F.	About 50 cm³/sec of air used to sweep out H_2 and O_2 from decomposition of water	**HYPO**, High-Power Water Boiler (Los Alamos, New Mexico) (*8, 25*)
			Mercury		**Los Alamos Fast Reactor** (Los Alamos, New Mexico (*3, 16, 26, 27*)
			Liquid metal	A blanket of natural uranium around the core is the fertile material. 100 kw of electrical power produced	**EBR**, Experimental Breeder Reactor (Reactor Testing Station, Arco, Idaho) (*16, 28*)
				Mock-up for land-based atomic power plant	**PPA**, Preliminary Pile Assembly (Knolls Atomic Power Laboratory, Schenectady, N. Y.) (*38*)
"Russians are operating one plutonium plant somewhat smaller than Hanford."					**Russian reactors** (*39*)
6 in. of steel, about 3 ft concrete; 450 tons	Octagon, 11 ft high, 19 ft wide	Vertical control rods in form of Cd and Al sandwiches; negative temperature coefficient	Heavy water	Maximum thermal-neutron flux is 6×10^{13} n/cm²/sec; average fast-neutron flux is 7×10^{13} n/cm²/sec	**Low-Cost Low-Power** (North American Aviation, Inc., Downey, Calif.) (*29, 30*)
6 ft of barytes concrete and lead	Octagon, 17 ft dia., $9\frac{1}{2}$ ft high	2 boron, 1 cadmium rods	Light water, 3 helical coils of $\frac{1}{4}$-in. stainless-steel tubing; maximum flow rate 1 gal/min through each coil.	Maximum reactor solution temperature ~80° C. Surface flux of fast and thermal neutrons is about 10^{11} n/cm²/sec each	**Raleigh** (North Carolina State College, Raleigh, N. C.) (*32–34*)

Continued

Reactors in Design and Construction (Continued)

Name	*Classification*	*Remarks*
MTR, Materials Testing Reactor (Reactor Testing Station, Arco, Idaho) (16)	Thermal $>4 \times 10^{12}$	For study of materials exposed to intense radiations. Expected to be finished in 1952. Phillips Petroleum Co., Bartlesville, Okla., is the operator.
STR, Submarine Thermal Reactor (Reactor Testing Station, Arco, Idaho) (16)	Thermal Ship propulsion	A land-based prototype. Under construction. To be operated by Argonne National Laboratory and Westinghouse.
SIR, Submarine Intermediate Reactor (Knolls Atomic Power Laboratory, Schenectady, N. Y.) (16)	Intermediate Ship propulsion	Liquid metal used for cooling.
Aircraft (16)	Power	
HRE, Homogeneous Reactor Experiment (Oak Ridge National Laboratory, Oak Ridge, Tenn.) (16)	Homogeneous	Uses a liquid solution of fuel and moderator.
CP-5 (Argonne National Laboratory, Chicago) (16)	Thermal Heterogeneous Heavy water Research	Improved design to replace CP-3 in 1952. Fuel is uranium.
Production (16)		Additions to the Hanford Works. Three at the Savannah River Project. Heavy water will be used at Savannah River.

Knolls PPA have not been described.

If the neutron chain reaction is not self-sustaining, the assembly is termed subcritical. Exponential piles are subcritical assemblies, generally of the order of magnitude of $^1/_{10}$ the volume of the critical assembly. Such an assembly would not be a reactor, even though the term pile is used. Most exponential pile studies are classified; however, a thorough description of the one at the Oak Ridge School of Reactor Technology is available (5). During the war, the Germans did not succeed in building a critical reactor (6).

Nuclear reactors may be classified in a variety of ways depending upon whether the point of interest, for example, is the nature of the assembly or the use of the reactor. Generally, the following factors pertaining to the reactor materials and assembly serve to identify the type of reactor:

1. **Neutron energies** are thermal, intermediate, or fast.

2. **Fuel-moderator assemblies** may be homogeneous or heterogeneous.

3. **Fuel** for the reactor may be uranium (natural, containing 0.7% U^{235}), enriched uranium (containing additional U^{233}), U^{235}, U^{233}, or Pu^{239}.

4. **Moderator** materials may be graphite, heavy water, light water, beryllium, or beryllium oxide.

Another method of classification is based on the purpose to which the reactor is to be put. There are four major divisions of purpose. The first is research and experimental uses. The second is production for atomic bombs. The third is power, which may be industrial or military (shipboard and aircraft reactors and land-based prototypes). The fourth purpose is breeding.

The table given on pages 12–16 lists all those reactors that have already been operated, in addition to those in advanced stages of design and/or construction. The second column in the table lists, in this order, neutron energy, fuel-moderator assembly, moderator, purpose, power, and neutron flux in n/cm² sec. The neutron flux is thermal unless otherwise indicated in the table. The remaining columns of the table give all the details available about each of the reactors that is listed.

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The Future Reactor Program

There is enthusiasm about the homogeneous-reactor approach. In this type of reactor, instead of very carefully machined fuel elements made of very unusual materials—an extremely expensive procedure—the reacting parts will consist of a solution, or a slurry or mixture, of very fine particles. This is why it is called "homogeneous." This solution, or slurry, can be pumped through a tank in which the nuclear reaction takes place and then pumped out again—hot in two senses, temperature and radioactivity. The heat at high temperature can be used through a heat-transfer mechanism to provide steam, or in some other way be converted into mechanical or electrical energy.

The great virtues of the homogeneous design are that it avoids the complicated mechanical design of the heterogeneous type of reactor and should simplify the fuel reprocessing problem. The difficulties of fuel reprocessing are ever present. After a reactor has run for a while, there is an accumulation of fission products. These fission products are analogous to ashes from the burning of coal. When too many fission products accumulate, the reaction stops just as a coal fire goes out when too many ashes and clinkers clog the fire bed. It is necessary to provide a mechanism for removing the fission products, and apparently this can be more readily done for homogeneous fuel.

The second promising type of reactor design is the breeder reactor. I will try to explain breeding.

The intriguing possibility exists theoretically that a reactor might be made to create more fissionable material than it consumes. Roughly, here is the way it would work. It happens that when the fission process is going on in a reactor, a few extra neutrons come out of each fission so that, on the average three neutrons, we will say, come from the disintegration of each fissionable atom. One of these three neutrons goes to keep the chain reaction going, to cause another fuel atom to fission. Another neutron is required to convert one U^{235} atom into a fissionable form of atom which, in this case, would be plutonium. One neutron is left over. Actually, only a fraction of a neutron remains, but to make the arithmetic easy, we will say that one neutron is left over. This neutron could be used to produce one more fissionable atom from another atom of U^{235}. If this were done after each fission process, the atom lost originally would be replaced and one additional fissionable atom would be created. In other words, as the reaction proceeds more fissionable material would be produced than consumed.

This sounds so much like perpetual motion that I hasten to add that the process can go on only as long as there is an amount of U^{238} at hand. As an analogy, let me compare uranium with skim milk and cream. A reactor runs only on the cream. The skim milk, the U^{238}, is useless. In a breeder reactor, however, we can convert gradually part of the skim milk, the U^{238}, into cream, into a fissionable form, plutonium. Now this is well worth doing, because if we succeed we will increase the potentially available fissionable material by a factor which is a substantial part of 140. There is much excitement when a new oil field is discovered which increases the available oil supply by perhaps ten percent. Here we are on the verge of a discovery which may increase the uranium supply several thousand percent. This is really an exciting possibility.

It may not work. There are many difficulties in it which you people ought to be aware of. For example, the materials a reactor is made of absorb neutrons, steal them from the chain reaction. It is necessary to develop materials with sufficiently low absorption. Here is another difficulty. There must be an excess of plutonium converted from U^{238}, not just after use of fuel one time in the reactor but also after chemical processing and fabrication of the fuel. The excess from the reactor must be more than enough to cover losses in processing and fabrication. Of course, the losses have to be kept to a minimum.

This sketching of possibilities along with problems is enough to indicate why the breeder-reactor approach is particularly interesting. A breeder may be either a heterogeneous or a homogeneous reactor. The breeding process will work for either thorium or uranium. In the case of thorium, breeding will convert unfissionable thorium into fissionable U^{233}. As you see, breeding is a very versatile possibility.

A beginning has been made into these investigations with the Experimental Breeder Reactor, assembly of which was completed during the summer at the Reactor Testing Station in Idaho, and which is now being given preliminary testing. However, it may be many months before we get an indication of breeding performance from this reactor.

The third promising reactor design is that providing for a very high burn-up of fuel for each loading of fuel elements. The difficulties connected with chemical processing can be minimized by having the processing occur as infrequently as possible. If the reactor, complicated though it be, uses one change of fuel over a very long period of time, perhaps converting U^{238} into fissionable material and gradually burning up the U^{235} and the plutonium produced from it along with the original U^{235}, then high burn-ups become possible, and considerable reprocessing cost and loss can be saved. This is another approach which has long-term possibilities and one we shall exploit to the fullest.

—Lawrence R. Hafstad, Oak Ridge Summer Symposium
Oak Ridge, Tenn., September 5, 1951

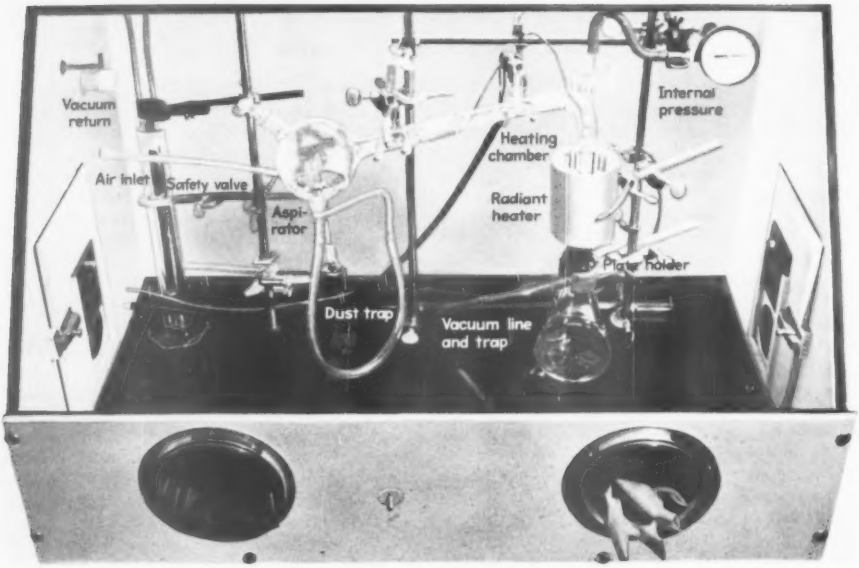

FIG. 1. The dust collecting apparatus used to deposit samples on the plates

Self-Scattering and Self-Absorption of Betas by Moderately Thick Samples

Correction factors for the effect of thickness of beta-active samples on counting rate have been determined. Results indicate that scattering into the counter predominates at low thickness, and self-absorption increases with thickness

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IN SPALLATION and fission-yield studies the problem of the effect of finite sample thicknesses on the observed counting rates of active materials has long been a perplexing one. To get absolute cross sections, samples containing inactive carriers are prepared which usually have a thickness between 1 and 20 mg/cm². Since no systematic data showing the effect of this thickness of sample on the observed counting rates have been available, corrections for self-scattering and self-absorption could not be made with any degree of certainty. Corrections of this type are essential, however, if absolute disintegration rates of any reliability are to be obtained.

Procedure

An investigation of self-scattering and self-absorption in salts having a wide variation in atomic number, and with radioisotopes having a broad spread of beta energies would be profitable.

To get data which were consistent over a wide range of beta energies, it was considered desirable that a single inactive salt be used as the self-scattering and self-absorbing medium in the sample. With this in mind, the problem was essentially one of getting a uniform, homogeneous deposit of salt containing a known amount of carrier-free active material mounted in a known area. The procedure used for obtaining this deposit should be such that successive layers of the same composition could be placed over the same area in approximately 1-mg/cm²

increments so that counts could be taken, and the self-scattering and self-absorption effects measured, at each increment. The apparatus used to prepare samples is shown in Fig. 1.

As finally developed, the technique of preparing the samples and measuring and self-scattering and self-absorption factor (hereafter called F_{ss}) was in three steps as follows.

1. Initial count. An aliquot (usually about 20,000 cpm) of solution containing the carrier-free active material was placed on a very thin (approximately 5 $\mu g/cm^2$) Zapon film, evaporated to dryness, and counted. This gave an initial count, C cpm μl, for the solution. It was assumed that there was no backscattering of beta particles from the Zapon film and no self-scattering or self-absorption by the carrier-free sample itself.

All counts used to obtain the self-scattering and self-absorption data were taken on shelf 2 (2.04 cm shelf-to-window distance) of the Geiger-counter sample holder shown in Fig. 2, using

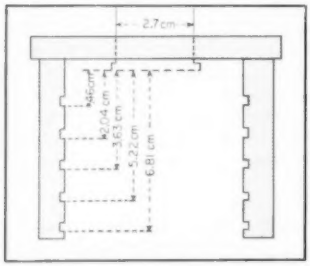

FIG. 2. Geometry of the G-M tube sample holder used in these experiments

an argon-chlorine filled Amperex model 100C tube. To check any variation in the self-scattering and self-absorption effect at other sample-to-window distances, several runs were made in which the sample was mounted on shelf 5 (6.81 cm shelf-to-window distance). No difference between the F_{ss} values on shelf 5 and those on shelf 2 were noticed which exceeded the experimental error (values for the two shelves checked to within $\pm 2\%$).

2. Backscattering factor. Stainless steel filters approximately 1.5 cm in diameter and 3 mm thick were obtained from the Micro Metallic Corporation of Brooklyn, New York.* This thickness is sufficient to give saturation backscattering with all beta energies used. These filters were washed repeatedly with 1*N* HNO_3 and distilled H_2O, dried at 130° C, and weighed. The washing, drying, and weighings were repeated until three successive weights agreed to ± 0.02 mg, after which the filter was placed in the dust collecting apparatus (described in step 3) and "filled" with approximately 1 mg/cm² of inert NaCl. The filled plates were then mounted directly below the Zapon film of step 1, as close as possible to the film without touching it, and a second count taken. This gave a count, C_0, which was higher than C because of backscattering of beta particles by the steel plate, i.e., $C_0 = F_b C$ cpm/μl, where F_b is the backscattering factor (*1, 2, 3*).

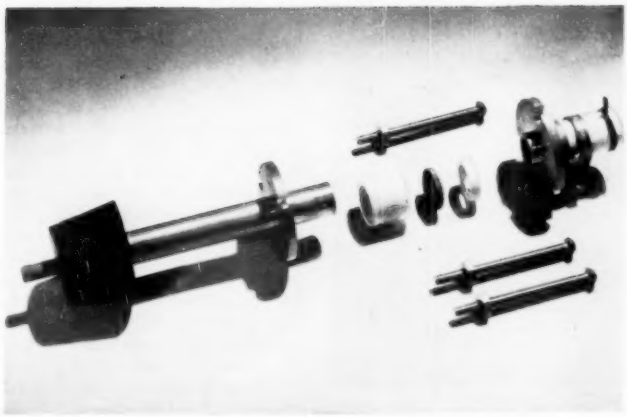

FIG. 3. Plate-holder unit of the dust collecting apparatus

3. Sample preparation and counting. A solution was made up of a precisely weighed amount of inert salt (NaCl or $Pb(NO_3)_2$) and an aliquot (usually about 150,000 cpm) of the solution used in step 1. This solution, after thorough mixing, was placed in the aspirator unit of the "dust" making apparatus shown in Fig. 1. The steel filter of step 2, washed to constant weight, filled with NaCl, and measured for backscattering, was placed in the plate holder unit inside the radiant heater shown in Fig. 1.

An exploded view of the plate holder unit is shown in Fig. 3 for clarity. Three white Teflon gaskets were used in the unit; one below the steel filter to form a tight seal with the lower brass fitting, one above the filter to form a seal with the upper brass fitting and to define the area over which the dust could be collected on the upper surface of the filter, and a third one to form a seal between the upper brass unit and the glass of the heating chamber. When assembled, the three bolts, fitted into slots in the brass fittings, were tightened and the steel filter was held rigidly in position between the Teflon gaskets.

Two Variacs, controlling the current to nichrome coils surrounding the heating chamber and the radiant heater, were turned on and enough time was allowed for the internal temperature of the heating chamber and plate holder unit to reach approximately 130° C.

Then a Megavac pump connected to the lower end of the plate-holder unit, and positive air pressure connected to the inlet tube of the aspirator unit, were turned on. Under normal

* The manufacturer claims that filters of this type will stop dust particles whose diameters are greater than two microns. In preliminary experiments with the dust collecting apparatus, a slight penetration of the untreated plates by active dust was noticed, probably due to a relatively low number of excessively large pores in the surface of the filter. When the plates were "filled" with a deposit of NaCl approximately 1 mg/cm² thick, penetration was not detectable either by anomalies in subsequent data or by physically milling off a thin layer of the steel filter. It was assumed, therefore, that all deposits collected on the NaCl-filled plates were on the surface and that there was no penetration of active material into the body of the filter.

FIG. 4. A 10-mg/cm² NaCl sample prepared in the dust collecting apparatus

running conditions there was a positive pressure of approximately 10 in. Hg on the air-inlet side of the aspirator, a negative pressure of approximately 5 in. Hg inside the aspirator and heating chamber, and a negative pressure of approximately 27 in. Hg on the vacuum-pump side of the steel filter. This pressure sequence caused the solution in the aspirator to be drawn through the aspirator nozzle and ejected as a mist.

The largest droplets were not carried by the air stream, and merely returned to the main body of solution, while the finest droplets were drawn into the heating chamber. Here, where the temperature was kept at approximately 130° C, the water was completely evaporated, leaving a residue of dust particles. The particles and the steam formed in the heating chamber were then drawn down to the filter, where the particles were collected and the steam passed through. When the apparatus had been run long enough for approximately 1 mg/cm² to have been collected, the steel filter was removed, cooled to room temperature in a dessicator, weighed, and counted.

The assumption was made that droplets ejected by the aspirator would have the same concentration of salt and active material as the parent solution. If this be true, then the specific activity of the dust particles should be known, since the ratio of isotope activity to weight of salt was known when the parent solution was made up. Therefore, if the salt has no self-scattering or self-absorbing effect on the beta activity, the specific activity of the particle is

$$C_1 = \frac{\text{number of cpm of activity added}}{\text{mg salt used}}$$

$$= \frac{\left(C_0 \frac{\text{cpm}}{\mu\text{l}}\right)(\mu\text{l used})}{\text{mg salt}} \quad \text{(from step 2)}$$

From the weight of salt collected and the number of counts observed on an individual sample, a specific activity, C_{obs} counts/mg, could be computed. The ratio of C_{obs} to C_1 would give the self-scattering and self-absorption correction factor for this beta energy and thickness of salt, i.e., $C_{obs} = F_{sss}(C_1)$.

This process of mounting in the apparatus, depositing a thin layer of salt, cooling, weighing, counting, and computing F_{sss} was continued with the same plate until a layer of approximately 20 mg/cm² had been built up. Salt deposits collected in this manner (a sample of which is shown in Fig. 4) usually were in the form of a very hard cake evenly distributed over a fixed area, and with quite sharply defined edges.

To minimize errors due to weighing, counting, or slightly uneven deposits, two separate plates were run on each

TABLE 1 — Salts and Beta-Active Isotopes Used for the Measurements

Isotope	Half-life	Maximum beta energy (Mev)	Salts used
S^{35}	87 d	0.167	NaCl, $Pb(NO_3)_2$
Pm^{147}	4 y	0.223	NaCl, $Pb(NO_3)_2$
W^{185}	73 d	0.43	NaCl
Pr^{143}	13.8 d	0.92	NaCl, $Pb(NO_3)_2$
P^{32}	14.3 d	1.7	NaCl, $Tl(NO_3)$
Y^{90}	65 h	2.2	NaCl, $Pb(NO_3)_2$

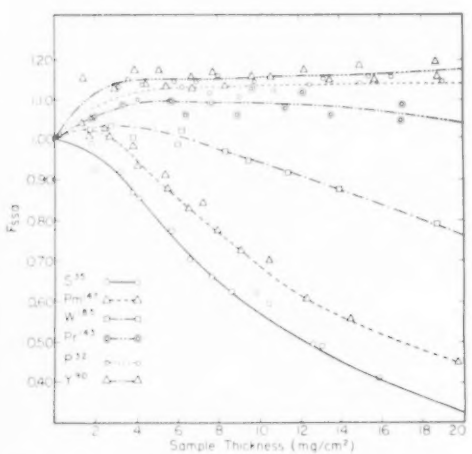

FIG. 5. The correction factor, F_{sss}, as a function of sample thickness for NaCl samples

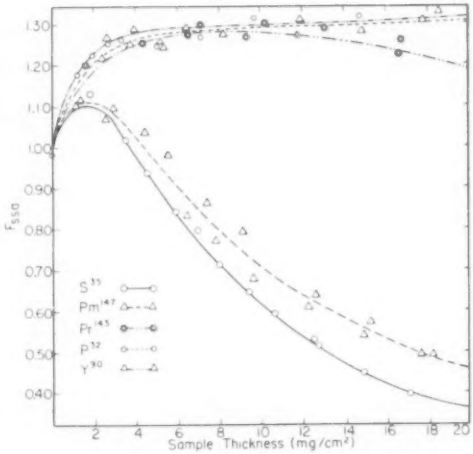

FIG. 6. The correction factor, F_{sss}, as a function of sample thickness for $Pb(NO_3)_2$ samples

salt and beta-energy combination, and an average of the results taken.

Results

Curves of the correction factor, F_{sss}, vs sample thickness were obtained for each of the carrier-free isotopes mixed with known amounts of NaCl and $Pb(NO_3)_2$. These salts were selected because they seemed to meet the necessary requirements for solubility and temperature stability needed in the atomizer and deposit-collecting apparatus. Six active isotopes were used in the experiments, pertinent data for which are summarized in Table I.

On the P^{32}-$Pb(NO_3)_2$ run it was noticed that the P-Pb compound (presumably $Pb_3(PO_4)_2$) had a marked tendency to stick to the glass walls of the aspirator unit. The $Tl(NO_3)$ did not behave in this manner and was used for the P^{32} run in place of $Pb(NO_3)_2$.

In the W^{185} run, both $Pb(WO_4)$ and $Tl_2(WO_4)$ formed insoluble precipitates* which prevented collection of a sample which had a known specific activity; therefore no high-atomic-number salt was used for this beta energy.

* The W^{185} solution, which was obtained from Oak Ridge National Laboratory, contained 14.8 mg ml W, 44.0 mg ml total solids, and 38.5 mg ml non volatile materials. This amount of W was enough to form a visible precipitate even when diluted 30:1 in the aspirator solution. The remaining five active isotopes were obtained in carrier-free solutions which contained negligible amounts of nonvolatile solid material.

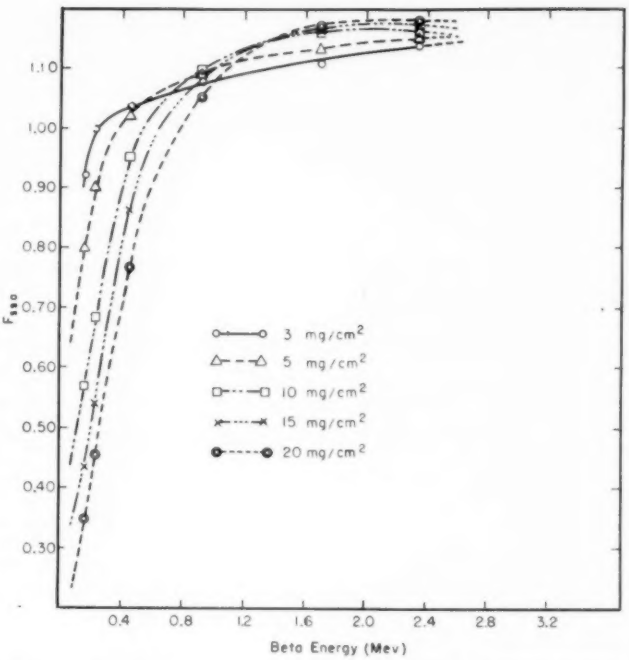

FIG. 7. The correction factor, F_{sss}, as a function of maximum beta energy for NaCl samples

Curves of F_{sss} plotted against sample thickness, which were obtained for NaCl and $Pb(NO_3)_2$, are given in Figs. 5 and 6. The two individual runs of any combination of salt and beta energy are plotted with the same symbol to facilitate reading of these charts. In most cases the difference between

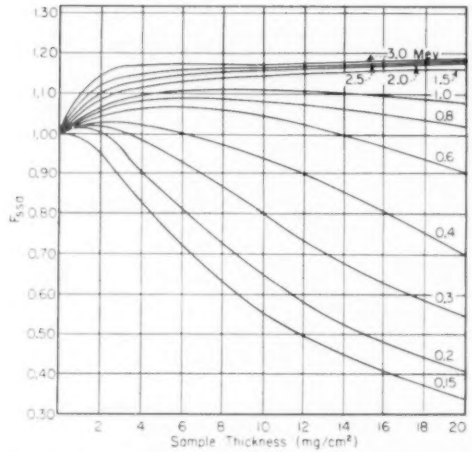

FIG. 8. The correction factor, F_{sss}, as a function of thickness of NaCl samples for convenient beta energies

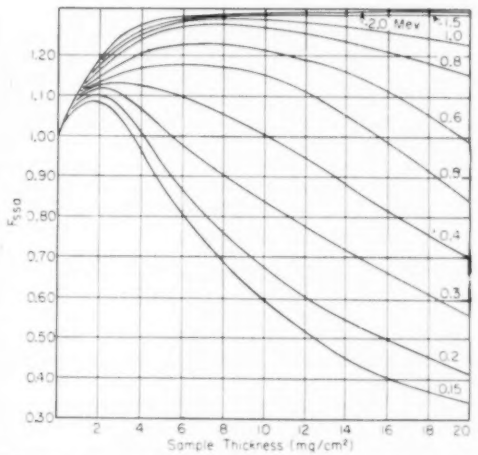

FIG. 9. The correction factor, F_{sss}, as a function of thickness of $Pb(NO_3)_2$ samples for convenient beta energies

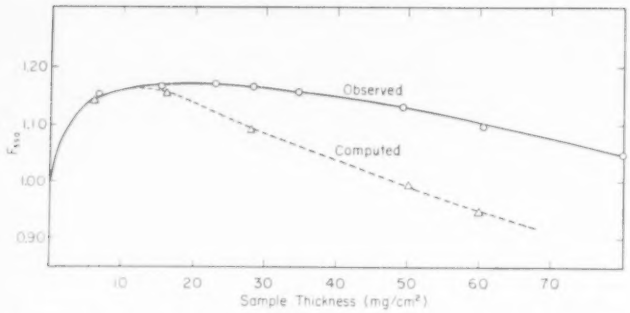

FIG. 10. The correction factor, F_{sss}, as a function of sample thickness for a thick NaCl sample and the betas from P^{32}

these runs did not exceed $\pm 3\%$, and there was no question as to where the average curve should be; in cases where the difference was greater than this, a curve was usually drawn half way between the individual curves.

To facilitate interpolation, it was considered desirable that curves be drawn for more even beta energy intervals. To do this, data on F_{sss} vs beta energy were taken from Figs. 5 and 6 for sample thicknesses of 3, 5, 10, 15 and 20 mg cm² and plotted as in Fig. 7. These data gave points for reasonably smooth curves, from which F_{sss} vs sample-thickness values were taken for beta energies of 0.15, 0.2, 0.3, 0.4, 0.6, 0.8, 1.0, 1.5, 2.0, 2.5, and 3.0 Mev, and plotted in Figs. 8 and 9.

All of the F_{sss} vs sample-thickness curves, of which those in Fig. 8 are representative, showed the same general characteristics. There was an initial rise in the F_{sss} factor for relatively thin samples, a leveling off, and then a gradual decrease in the factor as the sample thickness increased. Since scattering and absorption both affect the observed counting rate, this can only be interpreted to mean that self-scattering is by far the more important phenomenon in thin samples, and that self-absorption does not become critical until the deposit thicknesses approach an appreciable fraction of the half-thickness for beta particles in the salt. Thus, in Fig. 8, the curve for 0.2 Mev shows a maximum F_{sss} value of 1.02 at a sample thickness of 1 mg/cm². Since the half-thickness for 0.2-Mev beta particles is approximately 4 mg/cm² (*4*), absorption is noticeable at 2 mg/cm², and the curve shows predominantly an absorption effect for thicker samples, decreasing continuously to a value of 0.41 at 20 mg/cm². The curve for 1.5 Mev, however, where the half-thickness is approximately 90 mg/cm², shows a fairly rapid rise at low sample thicknesses, and has apparently just reached its maximum value of 1.16 at 20 mg/cm². Here the sample has not yet reached a thickness at which absorption plays an important part and the scattering effect is still a predominant one.

After the first few curves were obtained, an attempt was made to find a theoretical equation which would describe the data. The most successful one took the form

$$C_{obs} = (C_o/\lambda)(1 - e^{-\lambda t})(1 + Be^{-\lambda t}) \times [1 + b(1 - e^{-kt})] \quad (1)$$

where C_{obs} = counts observed; C_o = counts with zero self-scattering, self-absorption, and backscattering; $\lambda = 0.693/T_{1/2}$, where $T_{1/2}$ is the half-thickness in aluminum for beta particles of this energy (*4*); and B = backscattering factor for the plate on which the sample is mounted. The parameters k and b are analogous to a backscattering factor and absorption coefficient, respectively, for the salt with which the active material is mixed.

Preliminary trials showed that with proper adjustment of the constants b and k, curves could be obtained which would follow the experimental data quite satisfactorily between 0 and 20 mg/cm².

As a check on the reliability of this equation at higher sample thicknesses, and to find out how the higher-energy beta curves would behave in thicker samples, a NaCl-P^{32} run was made in which the sample thickness was built up to 80 mg/cm². The curve drawn for this run is presented in Fig. 10. Although the curve drawn from Eq. 1 (where $T_{1/2}$ = 105 mg/cm², B = 0.421, b = 0.27, and k = 0.19) follows the data fairly well up to 12 mg/cm², it turns down much too soon and gives low values for all thicker samples.

Since all subsequent attempts to fit the data to a theoretical curve failed, it was decided to use the curves in Figs. 8 and 9 to estimate empirically the self-scattering and self-absorption effect for beta particles in this type of sample. The procedure in use at the present time is as follows.

Samples are mounted on 1-mil aluminum dishes having a depth of approximately 1 mm and an area of 1 cm². The dishes are mounted on aluminum plates which are thick enough to give saturation backscattering for all beta particles observed, backscattering factors for which are obtained from Jaffe and Justus (*1*) or Burtt (*2*).

From the known weight of sample and an estimate of the area covered, the sample thickness may be computed. The accuracy of this value, of course, will depend on how evenly the sample is spread in the dish. Using Fig. 8 or 9 with the values for sample thickness, beta energy, and type of salt in which the activity is present, a value of F_{sss} can be estimated. Since it is obviously impractical to measure F_{sss} for salts of all atomic numbers, an interpolation is necessary between the values for NaCl and $Pb(NO_3)_2$. It is not to be expected that data obtained by this type of interpolation will have an accuracy better than $\pm 5\%$, but this accuracy should be satisfactory for all but the most precise absolute beta counting.

* * *

The authors wish to express their gratitude to Dr. E. Nielsen, Mr. M. Thaxter and the members of the Health Chemistry group of the University of California Radiation Laboratory for their aid in developing the apparatus used in these experiments, and to Drs. G. T. Seaborg, I. Perlman, and R. L. Folger for their interest and advice. This work was performed under the auspices of the United States Atomic Energy Commission.

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Handling of Radioactive Gold For Therapeutic Purposes

Medical therapy with this isotope requires a minimum of equipment and precautions, putting its use within the reach of smaller institutions. All necessary equipment and techniques are described

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DURING THE PAST three years radioactive gold-198 has been used in the treatment of several malignant conditions. While any attempt to evaluate this type of therapy at present would be premature, preliminary reports appear encouraging (*1–6*), and the use of this method continues to spread.

This article describes laboratory instrumentation and methods used in the therapeutic handling of gold-198. The installation of the laboratory, the design of the instruments, and the development of the handling techniques is based on the experience of the Washington University group, gained over a period of three years. The reader who is unfamiliar with the therapeutic uses of Au^{198} can also refer to the excellent pamphlet available from Abbott Laboratories (*4*).

The commercial availability of Au^{198} already processed and sterilized has considerably simplified its use. A great deal of care is still required in its handling because of the dangers presented by the large amounts of radioactive material used. However, aside from the dangers of spillage (minimized by the short half-life of Au^{198}), handling Au^{198} is no more dangerous than handling radon seeds. The laboratory space and instrumentation necessary for the establishment of a radiogold program are minimal, as compared to an I^{131} program. Aside from a careful monitoring of the amount of radiation received by the personnel involved in the handling of this isotope, no difficult measurements or calibrations are required.

Assumptions. The following discussion is based on three assumptions:

1. The Au^{198} will be used as a colloidal suspension of metallic gold.
2. This suspension is not prepared in the laboratory but is purchased ready for injection as a colloidal suspension (such as supplied by Abbott Laboratories, North Chicago, Ill.).
3. The maximum amount of Au^{198} to be processed at any one time never exceeds 1,000 mc.

These assumptions correspond to the present situation in this laboratory. It is the opinion of the authors that small or medium-sized institutions will find it too wasteful of time and troublesome to prepare the colloid themselves. The problems raised by the handling of more than 1,000 mc of gold at one time are too complex to be undertaken by small institutions that lack proper equipment.

The handling of the radioactive colloid consists of three operations.

1. Dilution of the colloid with a given solution to the desired specific activity.
2. Transportation of the gold to the operating room.
3. Injection of the gold.

Laboratory Facilities

If the institution where the radioactive gold is to be used is equipped with an isotope laboratory, the facilities of this laboratory can, of course, be used for the handling of Au^{198}. However, if such facilities are not available, a small laboratory must be provided for storage of the gold, for dilution

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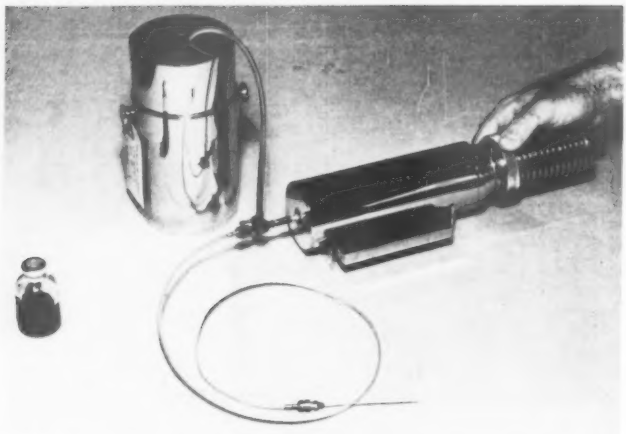

FIG. 1. Container for radioactive gold and shielded syringe

of the colloid to the desired specific activity, and for storage and decontamination of radioactive instruments.

This laboratory can be a small room that is not adjacent to any permanently occupied space; it should be equipped with a sink, a working bench, and a storage cabinet. Unlike the usual isotope laboratory, no hood is necessary here. The working bench should be about 3-ft high, 3-ft deep and at least 5-ft wide, and should be able to support at its center a weight of at least 500 lb. It is advisable to cover this bench with a thin sheet of stainless steel.

In the center of the bench a shielded area should be provided where the radioactive colloid can be diluted and transferred from one container to another with minimal radiation exposure to the operator. This space need not be larger than 2-ft square. A larger working area would require an unreasonable amount of shield material. The top of the bench under the working space should be shielded by a lead plate at least $\frac{1}{2}$-in. thick. The operator should be separated from the working area by a lead wall about 16-in. tall and 2-in. thick. On top of this lead wall a $2 \times 4 \times 8$-in. lead-glass brick is installed; this allows easy observation of the pipetting of the gold with minimal exposure to radiation. The field of vision through this glass brick is quite large because of the thickness of the brick and the high refractive index of the lead glass.

No other shielding is required if the nearest permanently occupied space is over 10 ft from the laboratory. When this condition is not fulfilled, it is necessary to provide a lead barrier facing the wall separating the laboratory from the occupied space. The barrier should be about $\frac{1}{2}$-in. thick, 16-in. tall, and 12-in. wide. The barrier should not be farther than 1 ft from the center of the working space.

A large mirror should be installed in such a position as to permit observation of all manipulations of the radioactive gold behind the protective lead barrier. It should be noted that the shielding protection described here is over-calculated, because, as will be explained later, the glass vial containing the radioactive gold is always handled in a lead beaker which reduces the radiation hazards considerably. It should be emphasized that the inverse square law is the most effective protective factor in the handling of radioactive materials; consequently, every effort should be made to handle radioactive sources by means of remote-control devices.

Equipment

Tongs, a remote pipetting device, special containers, and a shielded syringe all aid in keeping exposure of personnel to radiation low.

Handling tongs. A pair of long-handled tongs should be used in the handling of radioactive gold. Three sizes of tongs have been found convenient. For transportation of the source-containing beaker, tongs with a 70-cm handle, manufactured by Tracerlab, Inc., Boston, Mass., are used. For handling vials and test tubes, pliers-type tongs with 50-cm handles are used. For handling syringe needles, surgical tongs are used.

Remote pipetting device. It is essential to use some kind of remote-control system for the pipetting of radioactive gold. Various devices are available commercially. They can be divided into two main categories: supported instruments, mounted on a pivoting stand, and hand-held instruments. Our experience in this laboratory with a commercially-made, hand-held instrument has been disastrous. Use of this instrument has led to spillage and has been completely abandoned. A supported pipetting device manufactured by Tracerlab, Inc., Boston, Mass., is at present being used in this laboratory; it has proved very satisfactory.

Containers for radioactive gold. Two types of containers for radioactive gold are used in this laboratory. The first type is a lead beaker with a $\frac{1}{2}$-in. wall thickness. This is used as a protective jacket for the bacterin bottles in which the radioactive gold is supplied.

The second type of container (Fig. 1) is a brass-lined lead container which accomodates a 120-cm^3 glass jar. The opening in the lid of the container permits removal of the gold by means of a shielded syringe with minimal exposure. This container is fitted with a removable handle. A long handle fitted with a rubber cup that accommodates the screw cap of the glass jar permits the removal of the cap with minimal exposure.

Two of these containers are used in this laboratory. The radiation level at the surface of such a container loaded with 100 mc of gold is about 0.003 r/hr; lead thickness is 1.4 cm.

Shielded syringe. A shielded syringe is recommended for the injection of therapeutic doses of radioactive gold. The shielded syringe used in this laboratory is pictured in Figs. 1 and 2. The shielding consists of $\frac{1}{2}$-in. lead contained in a chrome-plated brass jacket. This structure accommodates a 50-cm^3 syringe which is operated by means of a screw device. A thin slit in the barrel permits observation of the scale by means of a mirror,

and a light bulb allows good visibility of the graduated scale.

This syringe is heavy and cumbersome. However, it provides excellent protection for the operator. The weight of the syringe, however, forbids its direct use. Hence a needle is connected to it by means of a 3-ft plastic tubing. A two-way valve permits the safe filling of the syringe from the gold container.

Monitoring Instruments

Two types of instruments should be used for the detection and measurement of ionizing radiations emitted by Au^{198}.

1. A portable dosage meter, sensitive to beta rays emitted by Au^{198} and gamma rays, with several scales covering a sensitivity range between 0.2 and 20 mr/hr, is needed. The detecting element of this instrument is either a thin-window Geiger counter or an ionization chamber. Several types of these instruments are available commercially. This instrument is used for checking the adequacy of the protection against radiations during the handling of the gold as well as the degree of contamination of any object which has been in contact with the radioisotope.

2. Several small pencil-type ionization chambers with a range of 200 mr are also required. Again, several types of these instruments are commercially available. They should be worn by the person handling the gold, and their reading will indicate the total dose of radiation received during the handling. It is recommended that such a chamber be attached to the sleeve of the operator, because the operator's hands are usually exposed to more radiation than the rest of his body. If the magnitude of the work involving radioisotopes so indicates, it is recommended that the pencil-type ionization chambers be replaced by film badges. Several commercial companies offer a fairly inexpensive film badge service, consisting of supplying the institution with a certain number of films, processing them after exposure to radiation, and determining the amount of radiation to which the film has been exposed.

Handling Au^{198}

The radioactive colloidal gold, as it is received from Abbott Laboratories, is sterile and contained in a bacterin vial having a volume of 5, 10, 20 or 30 cm^3, depending on the amount of gold shipped. This vial is contained in a lead safe housed in a wooden case.

Upon receipt of this case, the bacterin vial is quickly transferred to a lead beaker, where it remains either until the bottle is completely emptied or until the radioactive gold has decayed to the point where it can be disposed of safely. Several of these lead beakers are kept on hand.

The lead beaker containing the bacterin bottle is then placed behind the lead barrier on the isotope-laboratory bench. Two sterile syringe needles are inserted through the rubber cap of the bottle as shown in Fig. 3. One of these needles is kept above the level of the gold, and the other reaches the bottom of the bottle. The short needle is connected by means of rubber tubing to a 50-cm^3 syringe mounted in a holder on the operator side of the lead shield. The long needle is connected to the barrel of a 10-cm^3 syringe that is held by a ring stand in a vertical position above the bacterin bottle. Surgical tongs are used to insert the needles.

The needles and the syringes are

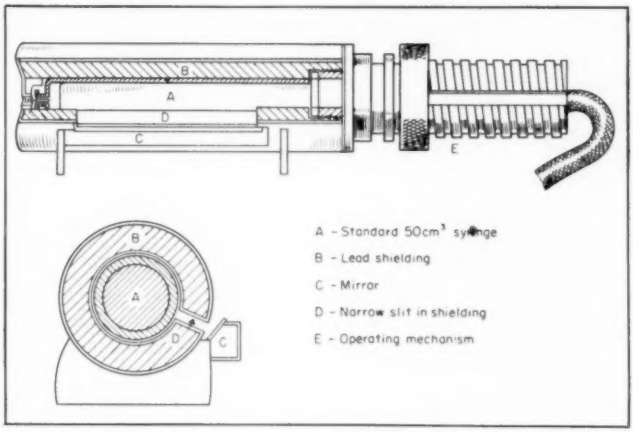

FIG. 2. Details of the shielded syringe

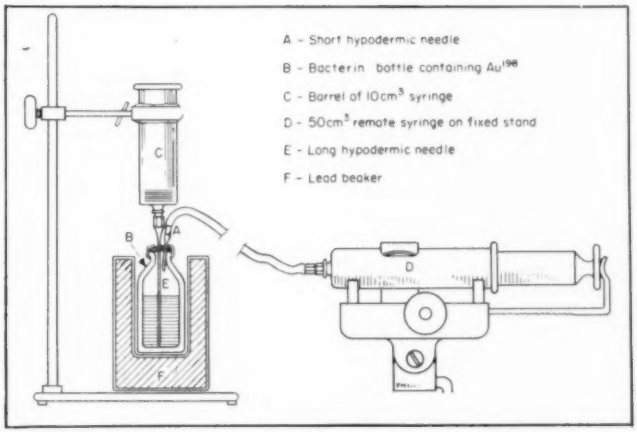
A - Short hypodermic needle
B - Bacterin bottle containing Au¹⁹⁸
C - Barrel of 10cm³ syringe
D - 50cm³ remote syringe on fixed stand
E - Long hypodermic needle
F - Lead beaker

FIG. 3. System used to withdraw radioactive colloidal gold from a bacterin bottle

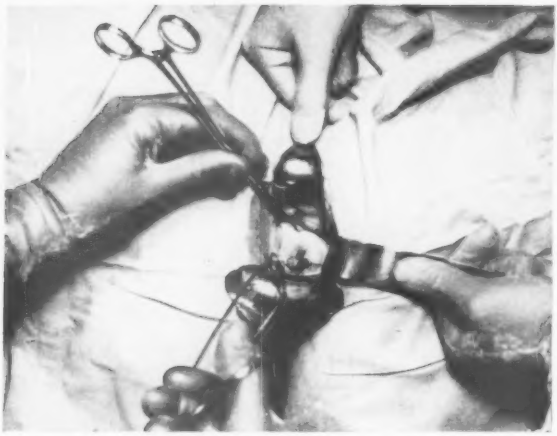

FIG. 4. Parametrial injection of radioactive colloidal gold

FIG. 5. Sites of injection in the parametria

sterile. Since the radioactive gold is supplied in a sterile form, no further sterilization is necessary.

This installation permits easy withdrawal of any given amount of gold. The procedure is simply to inject sufficient air into the bacterin bottle by means of the syringe connected to the short needle to raise the level of the colloidal solution in the barrel of the syringe above the bottle. From here the gold can be pipetted with a sterile remote-control pipette.

The remaining solution is drawn back into the bacterin vial. At this stage, in this laboratory, an aliquot of the colloidal suspension is withdrawn and calibrated. However, in most cases this operation is not necessary, because the gold shipped by Abbott Laboratories is already calibrated. From the known half-life of Au^{198}, a quick evaluation of the specific activity of the colloid can be made.

The quantity of gold to be injected is transferred (pipetted) into the previously described sterile 120-cm³ glass jar contained in a lead beaker. Saline or pectin solution is then added to bring the specific activity of the suspension to the desired value.

The total exposure to radiation experienced by a right-handed operator performing these operations was 20 mr on the right wrist, 5 mr on the left wrist, and 0 mr (unreadable) on the chest. These values are only rough approximations as measured with three Landsverk pocket dosimeters and a Tracerlab "Cutie Pie"; they may be in error by as much as 200%. The operator withdrew 100 mc of the colloidal gold from a 30-cm³ bacterin vial that contained half of a 1,070-mc shipment; ½ cm³ of the colloid was used for calibration purposes.

Operating Room Techniques

The gold thus prepared is brought to the operating room where the glass container is opened with the remote device previously described. The lid of the lead container is then replaced, following which a plastic tubing with a weighted end is lowered into the colloid through a hole provided in the top of the container. This tubing leads to the three-way valve that connects it to the shielded syringe.

Injection of the colloid. The clinical application of radioactive colloidal gold has followed three main procedures: intraparametrial injections, intracavity injections (for pleural effusions and ascites), and direct injection into tumor masses such as vaginal metastases and breasts. Using the shielded syringe in the manner outlined, no extra equipment is required.

The parametrial injections are usually performed in the operating room under general anesthesia, although in some cases it has been performed under local anesthesia. After preparation of the vagina by a soap and water wash and bichloride of mercury rinse, the patient is draped. The cervix is held with a tenaculum and the fornix to be injected is exposed, as shown in Fig. 4. A 21-gage spinal needle connected to the syringe by polyethylene tubing is then inserted alongside the uterus about 1 cm from the cervix. Once the needle is in satisfactory position the gold is injected slowly as the needle is gradually withdrawn. Two other sites are usually chosen 1–2 cm further laterally, and the needles are directed laterally slightly above and below the level of the first site in the plane of the uterus. The same procedure of injection is repeated on each side. These three sites of injection on both sides, as demonstrated in Fig. 5, have been shown to give a rather uniform distribution of the gold throughout the parametrium.

For intraperitoneal and intrapleural injections, the following procedure has proved to be effective. Having prepared the area of injection in the usual manner for a paracentesis or thoracentisis, enough fluid is withdrawn to make the patient comfortable. The gold is then injected, by means of the shielded syringe, through the needle used for tapping. At an interval of 7–10 days following this injection, the patient is again tapped and as much fluid as possible is withdrawn. In those cases where no fluid is present, the gold is injected in a total of 500–1,000 cm³ of normal saline solution. In all cases the patients are turned from side to side and changed from prone to upright positions several times immediately following the injection and are encouraged to remain active thereafter.

The size of the tumor and its consistency usually dictates the type of

needle used for direct infiltration of gold. Uniform distribution is obtained by gradual infiltration as the needle is moved through the tumor. For the more friable types of tumors, suspensions of the gold in a 2-3% pectin solution will decrease the leakage at the puncture site.*

Contamination

Great care should be exerted to avoid any direct contact between the colloid and the skin of the patient or of the operator, since such spillage may result in a severe burn due to beta rays. If such an accident happens, the colloid should be washed off with water before it has time to dry, because the dry colloid is very adherent.

The precautions to be observed after injections are outlined later.

Disposal of contaminated items. Utmost care should be exerted throughout the handling of the gold to avoid any contamination by spillage of the colloid. Such a spillage can be easily avoided during the transfer and the dilution of the gold. However, this is not the case in the operating room where, aside from the unavoidable contamination of a certain number of sponges, gloves, retractors, and various surgical instruments, occasionally a towel or sheet will be stained by the gold in spite of all precautions taken.

The surgical instruments are carefully washed by a nurse who has received special instruction in radiation hazards. Usually colloidal gold does not adhere to polished surfaces, and a mild brushing will get rid of most of it.

The case of gloves, towels, sheets, and sponges is quite different. Colloidal gold cannot be easily washed from porous surfaces. Hence all these items should be stored in some remote cabinet until the activity has decayed to a tolerable level. A period of six weeks will be required to reduce the activity by a factor of about 30,000. After this time all the items should be checked for activity by means of the portable dosimeter. The activity detected should be below 0.1 mr/hr. If this condition is fulfilled, the items to be discarded (sponges) can be disposed of in the usual way; the other items can be washed and re-used. If the radiation level is higher than 0.1 mr/hr, these objects should be left until a safe level of activity is reached.

The Radioactive Patient

A patient injected with about 200 mc† of colloidal Au^{198} presents a certain radiological hazard which, although usually overestimated, is quite real and should therefore be taken into account. Colloidal gold as it is currently prepared for therapeutic uses, when injected intraperitoneally, intrapleurally or intraparametrially, is not excreted to any appreciable degree.‡

Vaginal bleeding in a patient injected intraparametrially with Au^{198} could, in certain cases, carry some activity, but this was never observed in this hospital. The blood of such origin should be checked for activity, and in the case of a positive finding—activity higher than 0.1 mr/hr—the contaminated objects should be disposed of as described previously.

The radioactive patient does not have to be isolated in a private room; however, his bed should be separated by at least 3 meters from any permanently occupied space, that is, adjacent beds. At this distance the level of radiation will be about 5.3 mr/hr, the permissable dosage rate being 6.25 mr/hr (7).

Protection of nurses. The actual nursing of the patient will present a problem because the body of the nurse will often be as close as 30 cm from the radioactive area. The radiation level at this distance is about 0.53 r/hr; in other words, the weekly dose for this nurse will be reached in about 30 minutes. In many cases the hand of the nurse will be even closer than 30 cm from the radioactive areas; however, hands may receive a much higher dose of radiation than the whole body without ill effect.

There is no complete solution to this problem. However, there are several rules which will minimize considerably the radiation danger experienced by the nurse.

1. No one single individual should be allowed to nurse a radioactive patient closer than 1 meter more than once a week. The nurses taking care of such a patient should be rotated in order to distribute the exposure to radiation over a large number of people.

2. All nursing care of a radioactive patient should be reduced to a strict minimum.

3. All nurses attending a radioactive patient should be monitored for possible overexposure to radiation by means of either a pocket dosimeter or a film badge.

4. All these rules should apply for a period of at least 10 days after the injection of the radioactive gold.

The present discussion of the problem involved in the nursing of a radioactive patient may appear pessimistic. A factor which alleviates the situation is that the figure of 200 mc used for these calculations does not correspond to an average dose of gold, the average dose being about 100 mc. Besides, the half-life of Au^{198} is quite short, 2.7 days, and after this period of time the radiation level around the patient will be reduced by a factor of two.

However, it is the opinion of the authors that in view of the increasing medical use of radioisotopes, the problem of radiation protection should be strongly emphasized.

* * *

This work was supported by the U. S. Atomic Energy Commission. The authors wish to express their appreciation to Mr. C. Richard Hullihen for the design and the construction of the container for the Au^{198} and for his very helpful comments concerning the practical handling of the radioactive colloid.

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* The total amount of radiation received by the operator during such procedures as described here varies between 5 and 20 mr.

† This dose of 200 mc has been selected as being an upper limit of the therapeutic dose used at present. The present discussion will not apply to higher doses.

‡ It should be noted that this remark applies only to radioactive colloidal gold as it is at present prepared by the Abbott Laboratories. A colloid prepared following a different procedure would probably show a different distribution of size of the colloidal particles and could conceivably behave differently, especially if the colloidal particles were smaller in size.

HOW TO GET

Good Gross Autoradiographs

By W. E. LOTZ,*
J. C. GALLIMORE,†
and GEORGE A. BOYD*†

ADVANTAGES . . .

Bone sections prepared by the methods described result in:

- Better contact between film and bone to insure better image definition
- Sharper boundary lines because radiation from edges of bone is decreased
- Sharper images because thinner sections eliminate diffusion caused by radiation from deep in bone
- Use of inexpensive cardboard film cassette for exposure

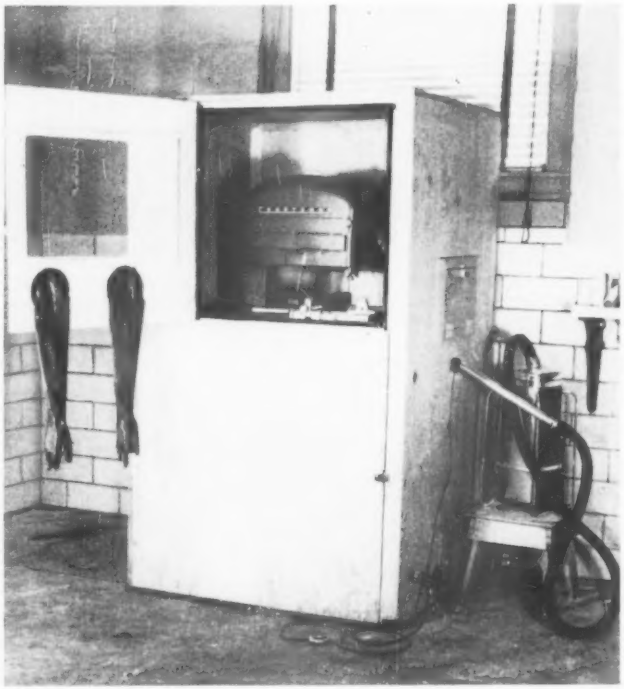

FIG. 1. Glove box housing band saw for sectioning

THE NEED for a simple method of obtaining high-resolution gross autoradiographs of large undecalcified bones has been emphasized by interest in studies of bone physiology as related to nutrition, investigations of the deposition and removal of fission products and heavy elements from the skeleton,[1] and exploration of radioisotope deposition in the bones of men experimentally treated for cancer.

The major requirement of such a method is the preparation, with little or no smearing of radioactivity, of bone sections with even thickness (about 2 mm) and smooth surfaces, which retain their normal morphology.

An important attendant problem is prevention of inhalation by personnel of the fine radioactive bone dust produced during sectioning.

Apparatus

Almost any well-constructed commercial band saw can be used for the sectioning. Selection of blades and their handling is of primary importance. A metal cutting blade, $\frac{1}{4}$-inch wide with 15 teeth to the inch, is suitable.

Smooth surfaces are produced when the blade runs without a whipping motion. Whipping produces striations along the bone surfaces that may be undesirably reproduced on the image. This behavior is a result of imperfections in the welding of the blade joint at time of manufacture. Consequently, it is important to select the blades carefully.

The entire saw can be housed in a glove box, as shown in Fig. 1. This avoids contamination of the laboratory and inhalation of radioactive bone dust by personnel. A viewing window above the glove ports is provided. Doors permit cleaning and removal of the cut sections. All door jambs are weather-stripped with rubber and felt stripping.

A commercial vacuum cleaner is used to maintain a slight negative pressure and to keep the dust at a

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# of Large Undecalcified Bones

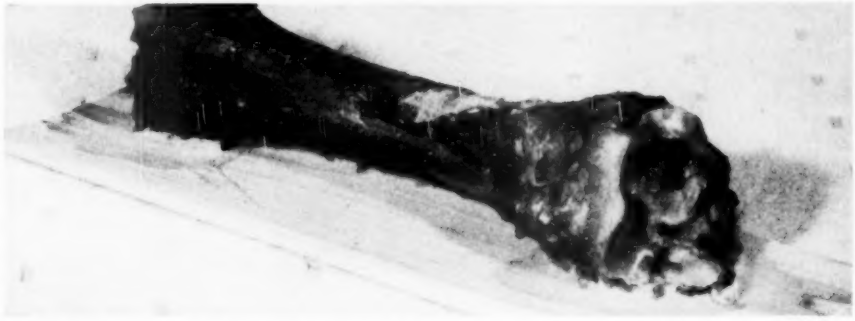

FIG. 2. Bone mounted with Duco cement preparatory to sectioning

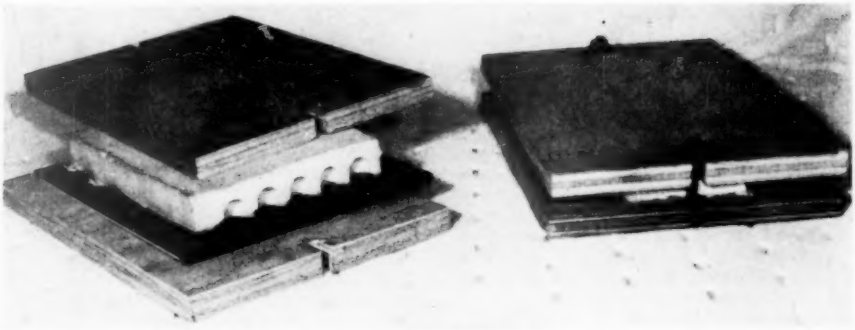

FIG. 3. Exposure presses showing cassette and sponge rubber in place

minimum within the glove box during the sectioning.

The band saw itself is mounted on a sliding track within the glove box. This facilitates cutting bones of different lengths. For instance, if small bones are to be sectioned, the saw is drawn forward to eliminate an awkward reach.

Preparation for Sectioning

The freshly excised bone is cleaned of excessive tissue. Removal of the periosteum is carefully avoided since there may be localization of related activity in this region.

To facilitate the cutting of straight uniform sections and to lessen the possibility of injury to the operator, the cleaned bone can be handled by one of two methods: (1) It can be mounted on a $\frac{1}{4}$-inch soft board with Duco cement, with care being taken to align the longitudinal axis of the bone parallel with the straight edge of the board, as shown in Fig. 2 (the cement is allowed to dry overnight); or (2) it can be mounted in plaster of Paris. The latter method is more laborious than the Duco cement technique, but because of the rapidity with which the plaster hardens it is possible to section a specimen within 30 minutes after embedding. This is particularly desirable when the specimen contains a short-lived isotope.

If desired, histological sections possessing reasonable cellular detail can be made from the sections after they have been used for autoradiographic exposure. With such use in mind, the sections must be mounted immediately after removal from the animal. The plaster mount containing the specimen must then be frozen in Dry Ice immediately after the plaster has hardened and sectioned while frozen. The autoradiographic exposure must be made in a deep freeze.

The essential steps are as follows: Water is added to the plaster of Paris until a semi-liquid consistency is reached. The specimen is placed in the plaster and aligned. To shorten the drying time and facilitate observation during the sectioning, only sufficient plaster mixture to immobilize

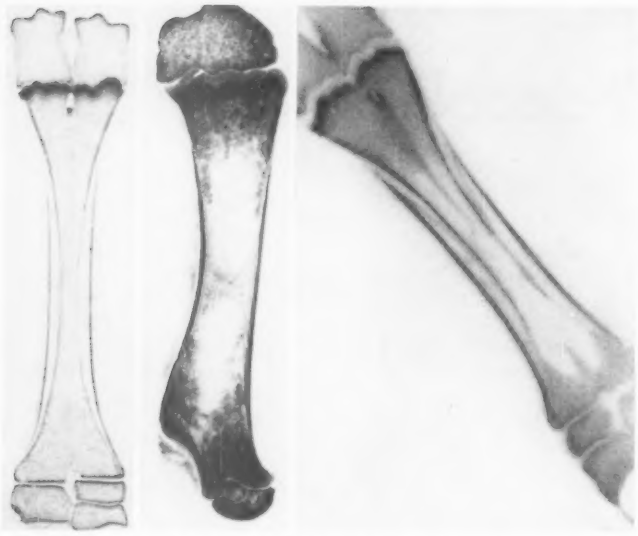

FIG. 4 (left). Metatarsus of a calf given 0.5 mc of Ca^{++} orally

FIG. 5 (center). Femur of a pig given 0.25 mc of Ca^{++} intravenously

FIG. 6 (right). Metatarsus of a steer given 4.85 mc of $Sr^{90}Y^{90}$ orally

the bone should be added. This usually results in a mount not more than two inches thick. The plaster is allowed to harden for approximately 30 minutes before removal from the mold.

Sectioning can be done at this time if histological sections are not required. If the latter are to be made, the mount is packed in Dry Ice before sectioning for approximately two hours, depending upon the specimen size. Immediately after a section has been obtained from the specimen it is placed upon and covered with crushed Dry Ice to prevent thawing. The sections are cleaned by scraping with a steel spatula to remove frozen tissue projections resulting from surface thawing caused by the elevated temperature of the band-saw blade. Scraping also removes plaster particles distributed over the surface of the section by the blade. The autoradiographic exposure is made in a deep freeze at a temperature of $-15°$ to $-20°$ C. If the exposure is satisfactory, the section is placed in a histological fixative for routine histological technique.

Sectioning

A straight section of uniform thickness is obtained by forcing the straight edge of the board or plaster of Paris block against the guide on the sawing platform which is adjusted to give the desired thickness. It is necessary to feed the bone with a slow uniform motion to avoid the tendency for the blade to bow outward and produce a curved surface.

Before the sections are removed from the glove box, they are cleaned of excessive bone particles by means of a nozzle attachment on the vacuum cleaner. The sections are removed through the side door. Prior to placing in the exposure cassettes, the bone sections are cleaned by scraping with a flat steel spatula followed by careful brushing with a soft-hair brush.

Autoradiographic Exposure

Individual light-tight cassettes (Kodak X-ray Exposure Holders) are used to house the bone during exposure. To protect the holder against contamination, a thin piece of cardboard or paper towel is placed between the holder and section. To prevent the possibility of chemical fogging of the film or contamination by tissue during exposure, the thin section of bone is placed on the cardboard and covered with a thin sheet of Pliofilm approximately 0.8 mils thick. This separates the bone from the film.

Preparation for exposure must be done in the darkroom under prescribed safe-light conditions. For exposure, Kodak No-Screen X-ray film is used because of its high speed or sensitivity and adequate resolving qualities. After the film is inserted, the cassette is closed.

As seen in Fig. 3, the cassette is then put into a plywood press for the duration of the exposure. A piece of sponge rubber $\frac{1}{2}$-inch thick is inserted to insure uniform contact between the film and bone section.

It is not the purpose of this paper to discuss in detail the exposure. However, some examples are given merely to serve as a guide in using the technique. The exposure time is a function of: (a) the type of radiation, (b) the energy of radiation, (c) the concentration of the isotope in the specimen, (d) the photographic processing and sensitivity of the film, and (e) the aim of the experiment. For discussion on some of these points, reference is made to Branson and Hansborough (*1*), Marinelli and Hill (*2*), Dudley and Dobyns (*3*), Dudley (*4*), and the photographic literature.

When a new study is initiated involving a different isotope or different chemical combination or a different tissue, the general plan of Marinelli and Hill of correlating monitor readings with a series of exposures for future guidance is followed. Together with this guide, a simultaneous exposure of two or three sections is started. Each is processed at different times to bracket the estimated exposure time. Because of a wide distribution of concentration in a single specimen, one autoradiograph may be many times overexposed at some points and underexposed at other points of interest. A series of different exposure times enables one to study each point of interest at the optimum photographic density.

Examples of exposure time. The following are examples of exposure times used with this technique. A series of ten pig femurs contained a range of 0.03 to 0.46 μc of $Sr^{90}Y^{90}$ per gram of epiphysis. Then sections from these bones were exposed 2 hours for over-all adequate autoradiographs for qualitative morphological study.

A similar series containing approximately the same range of activities of P^{32} were exposed 5 hours.

However, a similar range of activities

of Ca^{45} required 13 days. This striking increase of exposure time for Ca^{45} over the same range of activities of the other isotopes results from the difference in self-absorption for the different beta particle energies.

Human bones and soft tissues containing Ga^{72} activities ranging from 0.002 to 0.51 μc/gm were exposed 3 to 6 hours. The photographic densities for the lower activities were hardly adequate and could have been exposed safely for 2 to 3 half-lives (or from 29 to 44 hours). Longer exposures would have been unprofitable.

Upon completion of the required exposure the film is processed in X-ray solutions for the prescribed length of time.

Contamination Prevention

It is necessary to be certain that cross-contamination from one bone to another does not occur during sectioning. A way to check for this is first to section a piece of bone that does not contain radioactive material and expose it under the same conditions as the section which is subsequently prepared. If the control autoradiograph shows no darkening, there is reasonable certainty that a subsequent section will be free of detectable contamination from a previous cutting.

To avoid possible cross contamination, the band saw should be cleaned thoroughly and a new blade inserted before samples with a new isotope are sectioned, or before bones from a different series of animal are sawed. All parts of the saw, as well as the glove box interior, should be cleaned of bone particles and dust with the vacuum cleaner attached to the box. Following the vacuuming, the saw should be wiped with a damp cloth, giving particular attention to the parts that come in contact with the saw blade. Contamination of the rubber gloves is no problem since they are attached to and always remain within the glove box.

(In over 500 bones sawed and exposed in our laboratory, no signs of extraneous contamination were noted on the autoradiographic image when the method described was used. However, an acrid odor was noticeable at times during the cutting operation, but no radioactivity was detectable by an air-sampling device placed near the outlet of the vacuum cleaner or at various other locations within the laboratory.)

Typical Autoradiographs

The type of autoradiograph produced by this method is illustrated in Figs. 4, 5, 6, and 7, which are indicative of the adequacy of the process.

Figure 4 shows an autoradiograph of a metatarsus of a calf given 0.5 mc of Ca^{45} orally. This section was exposed for 15 days. Note the high resolution of the narrow black lines representing the location of the Ca^{45} with its low-energy beta particles in the periosteum. The many small diameter black spots representing the trabeculae, e.g., in endosteum of the funnel, are resolved. The absence of cross-streaking in all parts of the autoradiograph is visual proof of absence of smearing during cutting.

FIG. 7. Distal portion of the femur of a human who had received 21 mc of Ga^{72}

Figure 5 is an autoradiograph illustrating the value of the technique in studying the deposition of Ca^{45} throughout most of the bone. This section was made from the femur of an 80-day old pig which received an intravenous injection of 0.25 mc of Ca^{45} 10 days prior to sacrifice. It was exposed for 13 days. In the slower-growing calf bone, from which Fig. 4 was made, the Ca^{45} was deposited in sharply delineated areas, whereas in the fast-growing pig, from which Fig. 5 was made, it was redistributed into the compact bone by exchange and into the subepiphyseal area during longitudinal growth. The technique differentiates between these areas of light shading representing lower Ca^{45} concentration and blacker areas representing areas of higher concentration. The resolution in Fig. 5 is slightly less than that in Fig. 4 because of the more diffuse distribution of the Ca^{45}. The low-density, irregular images exterior to the periosteum and proximal epiphysis probably represent the soft tissue which is difficult to remove from the periosteum of young bone.

Figure 6 is an autoradiograph of a metatarsus of a steer given an oral dose of 4.85 mc of $Sr^{90}Y^{90}$. The exposure, lasting 2 days, was started 21 days after the bone was removed from the animal so that equilibrium between Sr^{90} and Y^{90} could be reached. The resolution of the images resulting from the Y^{90} 2.35-Mev beta particle is not as good as that in Fig. 4 from the Ca^{45} 0.254-Mev beta particle. However, it is adequate for gross studies. In the case of high-energy beta particles such as the Y^{90}, relatively high resolution can generally be obtained by thin sectioning and good contact of a smooth surface with the film. Along the periosteum and endosteum, there are some broader lines of lower density, indicating failure of good contact.

Figure 7 is an autoradiograph of the distal portion of the femur of a young human who had received 21 mc of Ga^{72} shortly before death. This isotope emits both beta particles and gamma photons. The high resolution of the line representing the subepiphyseal growing area shows that, with a thin specimen, the beta particles are registered more efficiently than the gamma photons. For specimens above the infinite thickness of the beta particles, the ratio of gamma photons to beta particles is increased and the resolution decreases.

* * *

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Latest Developments In Scintillation Counting

- In the past year, new photomultipliers and circuitry have been developed
- Data have been obtained on afterpulsing and resolution
- Liquid, organic, and neutron-detecting phosphors have been investigated
- New ways have been found to use scintillation counters

AT A SYMPOSIUM devoted to any one topic, much usable information is presented. For this reason, NUCLEONICS has digested the papers and discussions presented at the Scintillation Counter Symposium held in Washington, D. C. on January 29 and 30, 1952.

The symposium originated with committees on nuclear instruments of the American Institute of Electrical Engineers and the Institute of Radio Engineers, and was sponsored jointly by AIEE, IRE, the Atomic Energy Commission, and the National Bureau of Standards.

The symposium was divided into four sessions. In the first, the emphasis was on photomultipliers; in the second, on phosphors. The emphasis of the third and fourth sessions was placed on coincidence counting and circuitry.

In future issues, NUCLEONICS will publish many of the complete papers.

First Session Papers

"Two new photomultipliers for scintillation counting," by M. H. Greenblatt, M. W. Green, P. W. Davison, and G. A. Morton, RCA Laboratories Division, Princeton, N. J. A photomultiplier with a large photocathode and another with high gain have been developed. The H-5037 tube has a $3\frac{1}{2}$-in. diameter cathode, and with its 10 dynodes and an over-all voltage of 1,000 volts, gives a gain of 10^6. A cylindrical electrostatic lens is used to focus electrons from the photocathode onto the first stage of the multiplier.

The type 4646 photomultiplier, with 16 dynodes and an over-all voltage of 2,000 volts, provides a gain of 10^9. It should be useful in the 10^{-8}–10^{-10} sec range. This tube has a $\frac{1}{2} \times 1$ in. cathode. Voltage pulses of about 40 volts can be obtained on a 200-ohm line.

Both of these new tubes have a sensitivity of 30–50 μa/lumen and an S-9 response.

In the discussion of this paper, G. A. Morton stated that the present space-charge-limited output of the 4646 of $\frac{1}{3}$ ampere will probably be raised to about 1 ampere as development proceeds. The width of a single electron pulse in the 5037 tube was given as 5×10^{-9} sec. R. Engstrom of RCA's Lancaster plant stated that production of the 4646 should start by this fall.

"Some observations on pulse-height resolution and photosensitivity," by R. D. Swank, Argonne National Laboratory, Chicago, Illinois. An experimental investigation of the effect of statistical fluctuations in cathode emission and gain per stage in a photomultiplier has been carried out. By varying the distance between a special combination of source and crystal used to eliminate nonstatistical variations and the tube, the pulse height could be continuously varied. Since the pulse-height distribution of the source was nearly Gaussian, the pulse-height resolution data were derived from the measured widths at half-maximum, using relations for a Gaussian distribution.

Defining the pulse-height resolution R as the reciprocal of the fractional mean square deviation of the pulse height for identical scintillations, then

$$R = N_e \frac{f}{1 + \frac{\epsilon}{m - 1}}$$

where N_e is the number of electrons in a cathode pulse, f is the fraction of these electrons reaching the dynodes (electron collection efficiency), ϵ is the statistical enhancement factor, and m is the stage gain. Or, lumping all factors attributable to the photomultiplier in one term F

$$R = N_e F$$

The resolution R was found to vary linearly with pulse height at small pulse heights but to level off toward a saturation value estimated at 20,400 for large pulse heights. This saturation value is believed to be the intrinsic resolution of the source. An ultimate standard deviation of 0.7% was found.

Fourteen 5819 tubes were examined for resolution with a small pulse height. To obtain a value of F, the same tubes were measured for total cathode emission using an NaI(Tl) crystal irradi-

ated by gamma rays. The cathode currents were measured with a vibrating-reed electrometer and, utilizing the measured d-c gain of the tubes, the cathode emission was reduced to absolute values. The average of all tubes gave a resolution equal to 45% of the number of cathode electrons. To accept this value on the basis of statistical theory, one must accept rather low values for either the electron collection efficiency or the dynode statistical parameters. However, more complicated processes not accounted for by the theory may be involved. A value of 64% was computed for f.

Errors influencing pulse-height resolution include the contribution made by afterpulses that occur from 0.8 to 1 μsec after the pulse is initiated. This error was minimized by varying the anode time constant. The results reported here were corrected for the statistical time variations in single-electron pulses.

"Scintillation spectrometry," by P. R. Bell, Oak Ridge National Laboratory, Oak Ridge, Tenn., was not presented. W. H. Jordan described the work being carried out in the Physics Division of ORNL. Variations in the resolution of photomultipliers is being studied. Coincidence spectrometers are being used to measure decay schemes, and an automatic device for changing the setting of a single-channel analyzer is being developed.

Dr. Jordan introduced Mr. R. Heath, who presented the results of spectrometer studies.

"Afterpulsing in photomultipliers," by D. W. Mueller, Los Alamos Scientific Laboratory, Los Alamos, N. M. In experimental work at Los Alamos, R. Lantner and R. Corwin observed small associated pulses following the main pulse produced by 75-kv X-rays incident on terphenyl in toluene. There was also a noticeable difference in background in the scintillator-photomultiplier output before and after the main pulse.

Further studies of afterpulsing and satellite pulses have been carried out, using several techniques. Examination of the afterpulses showed that a large fraction of them about 0.5 μsec after the main pulse correspond to or are slightly higher than single electrons from the cathode. A slow component of afterpulsing up to 10 μsec was also found. No marked change in afterpulsing was detected between room temperature and liquid nitrogen and liquid helium temperatures.

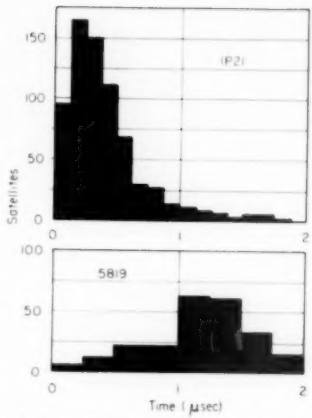

FIG. 1. Distribution of satellite pulses in photomultipliers (Harrison, Godfrey, and Keuffel)

A special tube, type C7151-B, furnished by RCA with silver magnesium dynode surfaces and better than normal outgassing, showed a negligible slow component of afterpulsing.

First Session Discussions

"Satellite pulses from photomultipliers," by F. B. Harrison, T. N. K. Godfrey, and J. W. Keuffel, Princeton University, Princeton, N. J. An investigation of secondary pulses that followed the main pulse in scintillation-counter experiments on meson decay showed that these satellite pulses originated in the photomultiplier. A comparison of two types of tubes was made; the distribution of satellite pulses in these tubes is shown in Fig. 1.

The amplitude and distribution of these pulses is consistent with their being caused by single positive ions,

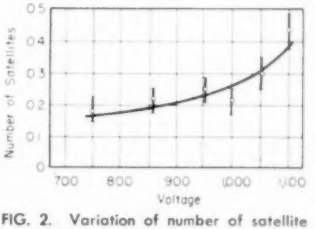

FIG. 2. Variation of number of satellite pulses in photomultipliers with gain (Harrison, Godfrey, and Keuffel)

produced by electrons of the main pulse, ionizing the cathode. Specifically, considering the ionization potential of the gas in the photomultiplier, the potential between the cathode and the first dynode, and the distance separating these electrodes, it can be computed that a positive ion would require 2 μsec to drift back to the cathode in the 5819 and $1\frac{1}{2}$ μsec in the 1P21. This does not explain, however, the afterpulses occurring at 10 μsec that were reported by Dr. Mueller.

It was found that the number of satellites does not vary linearly with the gain of the photomultipliers. As shown in Fig. 2, the number of satellites increases by a factor of 2 or 3 while the gain increases by a factor of about 20. This is taken as an indication that positive ions in the later stages of the photomultiplier dynodes do not contribute the major portion of the satellites.

"Afterpulsing in photomultipliers," by P. W. Davison, RCA Laboratories Division, Princeton, N. J. It has been found that afterpulsing may take one of two forms. The first has been found in 1P21, 4646, 4479, and C7151-B photomultipliers, and in a 5819 with a shield wrapped around the multipler cage. This first type of afterpulsing starts within 10^{-8} sec after the main pulse. The pulse rate dies out monotonically over a period of several microseconds. The number, but not the amplitude, of the pulses seems to be related to the amplitude of the main pulse. There is little, if any, change in the pulse-height distribution over the entire train. Visual comparison of the trains and pulses produced by single electrons seems to indicate that the pulse-height distributions of the two are identical.

The second, more complex, form of afterpulsing has been observed in an unshielded 5819 and in 5037 multipliers. Here too, pulses are seen to follow immediately after the main pulse, but the pulse rate increases during the interval immediately following the main pulse, rising to a maximum at $\frac{1}{2}$ to 1 μsec and then decreasing again over a period of 2 or 3 μsec.

The pulse-height distribution also changes with time. The first pulse after the main pulse corresponds in height approximately to single electrons from the photocathode. However, the pulse height increases, reaching a maximum at the same time that

the maximum pulse rate is observed.

It has been inferred that two separate mechanisms are involved in afterpulsing; the second type of afterpulsing is the combined effect of both processes.

The first process is very fast and has the appearance of delayed emission of a series of single electrons from the photocathode. Tests made on two 4646 multipliers with charcoal traps exhibited no change in the afterpulsing when the traps were cooled to liquid-air temperature. It is therefore doubtful that it is an ion effect. The cathode face-plate potential and light feedback from the anode to the photocathode were found to have no effect on the afterpulsing.

Further tests showed that light is produced in the vicinity of the andode when a pulse passes through the multiplier. These light flashes may be due to ionization of residual gas or to fluorescence of the mica supports. They have a rapid decay with a width at half value of about 5×10^{-8} sec. The flashes attributed to afterpulses had about the same width. In view of this rapid decay, it is difficult to see how the light flashes can account for the afterpulses out to several microseconds after the main pulse.

The second process may be an ion feedback between the later stages and the photocathode. The ions here involved are probably of low atomic number, possibly nitrogen. Cesium is probably not involved in this process.

Ion feedback is indicated because this effect is eliminated by placing a shield around the multiplier structure, and it only occurs in structures where there is a large photocathode that can see part of the back end of the tube.

"British photomultiplier tubes," by J. D. McGee, Electrical and Musical Industries, Ltd., London, England. A description of the venetian-blind-dynode photomultipliers manufactured by EMI was given. A 14-stage tube, type 6262, has recently been made available. This tube has a multiplication factor of 10^9 and gives 20,000 amp/lumen; the cathode is 2 in. in diameter.

A groove is tooled in the glass envelope of most EMI tubes between the photocathode and the dynode structure. This groove is painted with opaque paint to prevent light feedback from the dynode structure to the photocathode.

"Pulse-height resolution," by K. W. Robinson, RCA Laboratories Division, Princeton, N. J. Experiments have been performed to determine the enhancement in the width of the pulse-height distribution caused by a 5819 photomultiplier at narrow distributions.

A light-source tube consisting of an electron gun with a sharp cut-off characteristic and a phosphor with a decay time of less than $^1/_{10}$ μsec was used. Pulses about $^1/_2$ μsec long were applied to the control grid of the light-source tube to obtain scintillations.

The average number of electrons released from the photocathode by a scintillation is determined by measuring the ratio between the current to the anode of the light source and the photocathode current under d-c conditions. Then, by measuring the anode current with a known pulse rate, the average

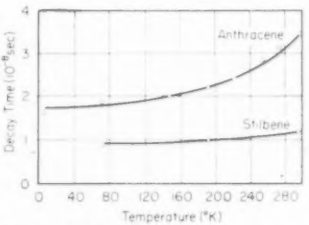

FIG. 3. Effect of temperature on decay time of fluors (Liebson)

number of electrons released per scintillation can be determined.

A potential of 200 volts was applied between the photocathode and the first dynode during these experiments. The pulse width was measured by finding the minimum setting of the channel width of a differential pulse-height selector where $^1/_2$ of the total number of scintillations would be counted. This measurement of the width corresponds to twice the probable error of the distribution. The number of electrons released from the photocathode was assumed to follow a normal distribution law with a standard deviation equal to the square root of the average number of electrons.

The experiments were performed with an average number of electrons per pulse varying from about 500 to 500,000, and the widths of the pulse-height distributions varied from about 7% to 0.2% respectively. Distributions as narrow as about 0.1% have been obtained. The average increase of the width of the pulse-height distribution due to the photomultiplier is a factor of about 1.3.

The increase in the width of the pulse-height distribution due to the photomultiplier is due to the statistical nature of secondary emission and the collection efficiency being less than 100%. Assuming a gain of 5 for the first dynode and the normal statistical enhancement factor of 1.5, the collection efficiency is found to be 82%. This is in agreement with other observations.

"Multiplier phototube problems," by R. W. Engstrom, O. Thuler, J. L. Weaver, and R. G. Stoudenheimer, RCA Victor Division, Lancaster, Pa. A blue-sensitivity test has been incorporated into production testing of photomultipliers, and a study of photocathode uniformity is being made preparatory to setting production limits. A production test consisting of a 5-spot check of cathode sensitivity is being tried out.

By using a Corning 5113 filter in conjunction with a tungsten light, the radiation of common phosphors can be approximated in production testing. Tubes having high sensitivity to tungsten light were found to have less relative sensitivity in the blue region. The new test places a lower limit of 2 μa/lumen for response to the blue region; previously, production had run as low as 0.5 μa/lumen.

In addition to these tests, studies are being made of the build-up time of excessive dark currents at high voltages. The time of build up varies with voltage, temperature, and internal shielding of the tube but is generally of the order of a few microseconds. This corresponds to the afterpulsing times mentioned in previous papers. The transit times of positive ions can be correlated with the measurements, and, contrary to previous papers, the cesium atoms definitely may enter into this phenomenon.

Second Session Papers

"High-energy particles and the scintillation counter," by L. F. Wouters, Radiation Laboratory, University of California, Berkeley, Calif. Scintillation counters are being used in experiments being carried out with high-energy particles from the accelerators at the Radiation Laboratory.

Scintillation counters, compared to the proportional gas counters previ-

ously used, provide much better energy discrimination as well as maximum usable speed. It is consistently possible to resolve particles originating during successive r-f cycles in an accelerator, thus giving a hundredfold improvement in the possible data collection rate.

By choosing the proper scintillator, it is sometimes possible to discriminate against unwanted background radiation. To detect heavily ionizing particles in a background of nonionizing radiation, however, the scintillation counter is not used because it acts as a converter for the background radiation.

Counter telescope arrangements are also used to eliminate the effects of the background.

"Crystal and liquid phosphors," by G. T. Reynolds, Princeton University, Princeton, N. J. Systematic studies of solid and liquid, organic and inorganic scintillating materials have been carried out. Ultraviolet spectra of the phosphors have been related to their response to particle radiation and to the photomultiplier detector. Decay times and energy response to various types of particles have also been considered.

Besides particle detection, scintillation counters also can be used for time-interval and particle-energy measurements. For timing measurements, the organic solutions and crystals have a clear advantage, their decay times being in some cases as short as a few mμsec. Energy measurements are best done with inorganic crystals such as NaI, which has a nearly linear energy response even when large ionization-loss rates are involved.

The energy transport phenomenon was discussed briefly.

"Neutron-detecting phosphors," by J. C. Schenck, Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tenn. A variety of phosphors containing lithium have been developed in which scintillations are caused by the products of the $Li^6(n,\alpha)H^3$ reaction. Over 300 samples of lithium-containing compounds were tested using ultraviolet and polonium-alpha radiations as well as neutrons.

Lithium disilicate activated with titanium gives counting efficiencies of 40% for thermal neutrons, but this phosphor has a decay time of 40 μsec. Cerium-activated $LiCaSiO_4$ had the shortest decay time of the phosphors tested.

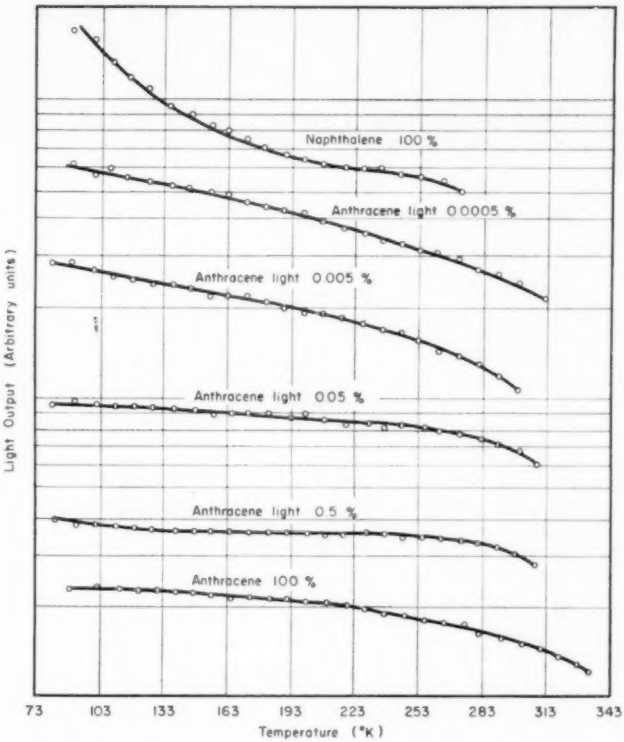

FIG. 4. Effect of temperature on light output of pure and mixed fluors (Liebson)

An attempt was made to use zirconium compounds, but the melting point was too high to allow growing of large crystals.

Lithium stannate, $Li_2SnO_3(Ti)$, was found to be a very efficient phosphor similar to $CaWO_4$, but Li_2WO_4 was found to be a poor phosphor.

The lithium halides were also tested. Tin-activated lithium iodide—LiI-(SnI_2)—gave 15% resolution at half-maximum for slow neutrons. Lithium bromide with 0.1% $SnBr_2$ is a colorless, transparent crystal that gives a 27% resolution and has a decay time of 1½ μsec.

Studies with LiI(Tl) and neutrons of different energies showed a marked peak in the response curve at 0.27 Mev. This is attributed to Li resonance.

"Temperature effects in fluors (phosphors)," by S. H. Liebson, Naval Research Laboratory, Washington, D. C. Decay times for X-ray scintillation pulses from organic fluors, detected by a photomultiplier, were measured with a shorted transmission line technique involving self-cancellation of the pulse. Results were in general agreement with previous experiments.

Decay times decrease as the temperature is lowered in anthracene and napthalene, but are essentially constant in stilbene, Fig. 3. Figure 4 shows the similar decrease obtained with mixtures of two phosphors—these results indicate that anthracene in naphthalene acts as an energy trap, the host lattice being primarily responsible for the variation of output with temperature.

To check the decay-time measurements, further measurements were made with an ultraviolet fluorometer. The phase shift between the fluorescent light and the incident ultraviolet light provided information from which the decay times were determined. While indentical decay times were found with

ultraviolet and X-ray excitation, these times were shorter than those determined from scintillation observations, as shown in Table 1. This discrepancy is not easily resolved; it may be due to excitation of upper energy states requiring more time for the energy to become available to the emitting levels.

Second Session Discussions

"Pulse height versus electron energy and crystal thickness," by W. Miller, J. W. Motz, and H. O. Wyckoff, National Bureau of Standards, Washington, D. C. With a monoenergetic beam of electrons incident on an anthracene scintillator, the most probable pulse height was measured as a function of the electron energy, in the range 0.2 to 10 Mev. The measurements were made with anthracene disks that were 0.170, 0.150, 0.102, and 0.052 in. thick. For electrons whose range is large compared to the crystal thickness, the pulse height decreases with energy, whereas the stopping power increases slightly with energy. This result may be interpreted in terms of the variation of actual path length in the crystal with electron energy.

"Properties of organic scintillators," by J. W. Irvine, Jr., Massachusetts Institute of Technology, Cambridge, Mass. A comprehensive examination of the properties of organic scintillators was made; some correlation was found with molecular structure.

Decay constants for some of these compounds are shown in Fig. 5. These results were obtained with Co^{60} gamma radiation impingent on the scintillator. Variations in the average pulse height are shown in Fig. 6; the effect of temperature can be seen.

"Organic chemistry of solution scintillators," by F. N. Hayes, Los Alamos Scientific Laboratory, Los Alamos, N. M. The effect of structural variation of organic solute and solvent molecules on the light output in homogeneous beta-excited liquid scintillators has been investigated. A series of polyaryls containing heterocyclic units including many compounds related to 2,5-diphenyl oxazole, have been synthesized whose toluene solutions give high relative light yields. A study of 23 simple aromatic solvents, all benzene derivatives, has demonstrated that the effectiveness generally increases with alkyl substitution and decreases with electro-negative substitution, provided, for the later case, that a strong electron-releasing resonance effect does not exist. Sulfur decreases the efficiency remarkably in all solutions studied.

The response rises in a linear manner with increasing activity of the homogeneous source. Increasing the depth of solution increases background and the net current due to external hard gammas, and decreases the net current due to C^{14} in the solution.

Data from photomultiplier current yields, and from absorption and emission spectra, is consistent with a theory that involves initial ionization steps followed by an energy transfer from solvent cations to solute molecules. The solute cations thus produced recombine with low-energy electrons to give activated scintillator molecules that subsequently return to the ground state with simultaneous emission of light.

"Activation of LiI crystal phosphors," by W. Bernstein and A. W. Schardt, Brookhaven National Laboratory, Upton, N. Y. Lithium iodide crystals have been grown with different activators and tested for pulse height and resolution with thermal neutrons from the BNL reactor. Utilizing a collimated neutron beam, the response of portions of thallium-activated crystals was studied; a correlation was found between response and the amount of activator present. Attempts to grow uniformly activated crystals by using growing speeds of 1.7 to 7 in. per day were unsuccessful.

TABLE 1 Decay Time of Fluors as Measured by Liebson

Fluor	Ultraviolet decay (sec × 10^{-8})	Gamma decay (sec × 10^{-8})
Anthracene	1.7	3.0
Anthracene (−195° C)	0.8	1.3
Carbazole	0.7	1.3
Chrysene	2.2	2.6
Diphenylacetylene	0.25	0.4
1,4 diphenyl butadiene	0.2	0.6
Fluoranthene	4.6	
Fluorene	0.88	
Perylene	1.2	
Phenanthrene	0.52	
Quaterphenyl	0.38	0.7
Stilbene	0.31	0.8
Terphenyl	1.1	0.6
½% anthracene in benzene	0.20 ± 0.55	
½% terphenyl in toluene	0.25 ± 0.05	0.2

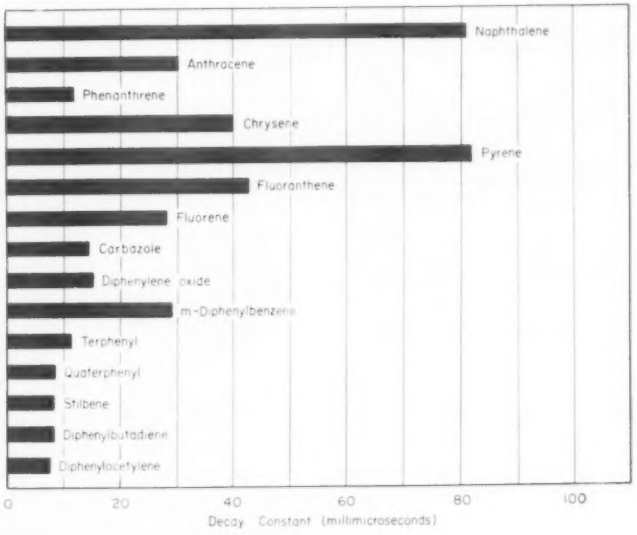

FIG. 5. Decay constants of organic scintillators (Irvine)

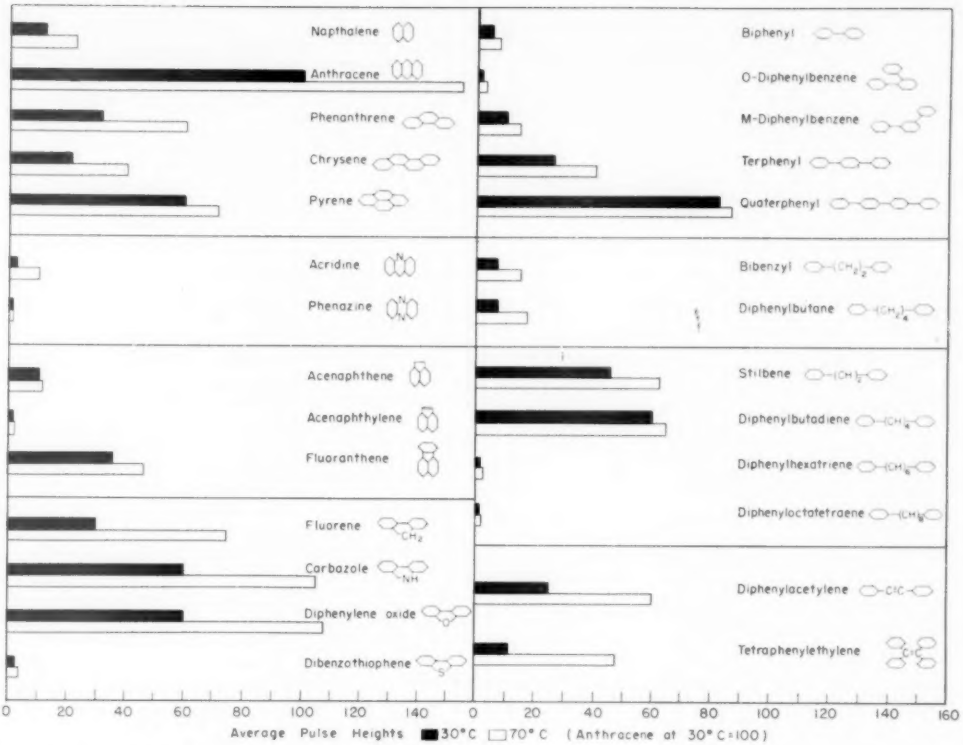

FIG. 6. Average pulse heights of organic scintillators (Irvine)

LiI(In) behaved very much like LiI(Tl); most of the activator was expelled from the lattice. The fluorescence band is a whitish orange and does not match the 5819 response.

Another crystal was grown with 0.3% AgI activator; this crystal was partly transparent. The pulse height was the equivalent of 210 kev; different sections of the crystal showed a pulse-height variation of 20%.

A crystal grown with 0.15% by weight $SnCl_2 2H_2O$ activator varied in color from transparent to opaque yellow; all but the most opaque part gave a uniform pulse height of 197 kev. The fluorescence band is in the green.

Larger crystals were then grown with the tin activator. Pieces of these crystals gave resolutions between 13.7 and 16.5% and pulse heights equivalent to 25 kev. The pulse height varied less than 10% between different pieces.

The bias and high-voltage curves obtained with these crystals exhibit plateaus as shown in Fig. 7; thus stability is not a prime requirement in circuits used with these crystals.

"Particle counting by Cerenkov radiation," by J. Marshall, The University of Chicago, Chicago, Ill. Cerenkov-radiation particle counters have been built for work with high-energy electrons, mesons, and protons. A description of these counters has been published in *Phys. Rev.* **81**, 275 (1951).

Cerenkov counters have also been used as threshold detectors for electrons, protons, and fast neutrons; the mediums used were water and Lucite.

"Scintillation counters and phosphors in England," by F. H. Wells, Atomic Energy Research Establishment, Harwell, England. Communications from G. Harding and J. V. Jelley were presented.

G. Harding has produced plastic phosphors by dissolving 1144-tetraphenyl 1-3-butadiene in styrene and polymerizing with benzyl peroxide

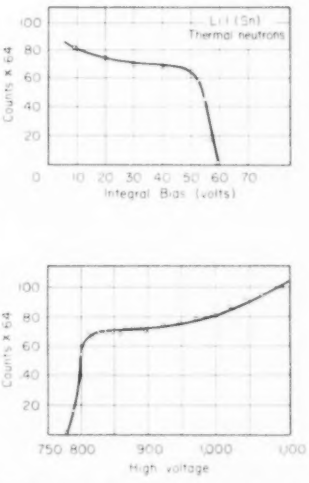

FIG. 7. Bias and high-voltage curves for photomultiplier used with LiI(Sn) phosphor show definite plateaus (Bernstein and Schardt)

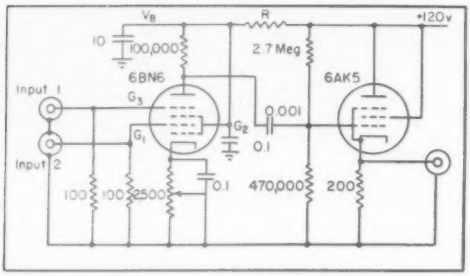

FIG. 8. Fast coincidence circuit using 6BN6 gated-beam tube (Marshall)

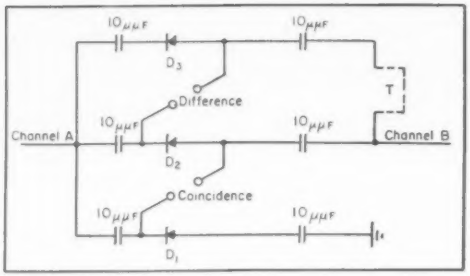

FIG. 9. Fast coincidence-anticoincidence circuit (Bay, Meijer, and Papp)

catalyst. Blocks as large as 500 cm³ have been made. The pulse height with electrons is 25% that of anthracene, and the decay constant is 8 μsec. Optimum concentration of the phosphor is about 1.5%.

Two types of fast-neutron detectors have been developed, the first using powdered KI(Tl) in bromonaphthalene, the second consisting of a pile of ten very thin films of KI(Tl) supported on mica and cemented together with polystyrene. Neutron efficiencies of 0.2% and 0.1% were obtained respectively when these detectors were exposed to 2.5-Mev neutrons and 2.62-Mev gammas, the efficiencies being obtained where the gamma counting rate was $\frac{1}{100}$ that of the neutron rate.

J. V. Jelley has developed a liquid scintillation detector with an area of 1,000 cm² and a depth of 15 cm. A silver-plated tank with a glass cover is used to hold a solution of 30 gm of para-terphenyl in 15 liters of pure benzene. An integrating cone of Al coated with deposited MgO powder is used to conduct the scintillation light to an EMI 5311 photomultiplier. With this assembly sandwiched between two trays of G-M counters, efficiencies of 91–98% were obtained in coincidence counting.

"Nonlinearity of $NH_4I(Tl)$ phosphor," by P. Gugelot, Princeton University, Princeton, N. J. A crystal of thallium-activated ammonium iodide was formed in a quartz container. This crystal was not suitable for use in a proportional scintillation counter for neutrons because it did not provide a linear relation between pulse height and energy.

"Slow-neutron liquid-scintillation detector," R. K. Swank, Argonne National Laboratory, Chicago, Ill., reported that C. O. Muehlhause and G. E. Thomas have found that methyl, ethyl, propyl, etc. borates can be added to a solution of phenylcyclohexane, terphenyl, or diphenylhexatriene without any quenching effect on the fluorescence. This allows detection of slow neutrons at very high efficiencies.

A solution of equal parts by volume of methyl borate and phenylcyclohexane gave an alpha pulse height of about 30 electrons at the cathode of a 5819 photomultiplier used with it; the neutron lifetime in the medium is about 0.4 μsec.

Third Session Papers

"Emission time of secondary electrons," by R. R. Law, RCA Laboratories Division, Princeton, N. J. Tests on developmental tubes using multistage electrostatic electron multipliers showed unexpectedly poor performance at high frequencies. The high-frequency performance is substantially independent of voltage, temperature, current density, modulation index, or dynode material. Dynode materials so far tested include MgO, BaO, BeO, and gold.

These results may be explained by assuming that each stage of the electron multiplier exhibits a simple exponential decay characteristic with a time constant of 3×10^{-10} sec—that is, that the fundamental process of secondary electron emission has this decay characteristic. If this is true, the half-amplitude width of the output pulse from a nine-stage multiplier into which a single electron is injected may be expected to be greater than 2×10^{-9} sec. Also, the gain of a multiplier will be reduced at high frequencies even if transit-time effects are reduced.

"Fast pulse circuit techniques for scintillation counters," by F. H. Wells, Atomic Energy Research Establishment, Harwell, England. The designs of some recent fast pulse-type circuits and associated test equipment used in England were described. Secondary emission types of amplifier pentodes are being used extensively in high-speed circuits and also in wide-band distributed amplifiers.

A recording oscilloscope has been constructed that records single time bases from 0.1 to 10 μsec on film. Fast coincidence circuits that provide good stability of the coincidence resolving time were also discussed.

"6BN6 fast coincidence circuit," by J. Marshall, Institute of Nuclear Science, University of Chicago, Chicago, Ill. To use the 6BN6 gated-beam tube as a fast coincidence circuit for short positive pulses, both control grids are biased beyond cutoff and the pulses are applied to these grids. If the pulses overlap, a pulse is produced at the plate of the tube; this is recorded as a coincidence count. The circuit is shown in Fig. 8. A high impedance is used in the plate circuit to lengthen the output pulse to about 1 μsec.

With square pulses from a mercury-switch pulser, resolving times better than 3×10^{-10} sec were observed. However, a skewed curve is obtained for output pulse voltage plotted against the delay between the input pulses applied. This can be attributed to feed-through of single electrons in the 6BN6.

In discussion of this paper, it was brought out that a transit time of 10^{-8} sec was indicated for the 6BN6 during work carried out at Columbia University. A delay time of 10^{-7} sec was found at the National Bureau of Standards. Dr. Marshall pointed out that the relation between true coincidence counts and resolving time depends on the pulse-height distribution

of the source; with 2×10^{-9}-sec pulses from the counter, 100% of the pulses can be counted without counting any of the background.

"Time measurements with coincidence circuits," by S. De Benedetti, Carnegie Institute of Technology, Pittsburgh, Pa. A simple delay-line coincidence circuit having a resolution of about 10^{-9} sec when used in connection with fast organic scintillators gave efficiencies of 28–50%. When resolution was tested by measuring the time of flight of gamma rays from Na^{22}, it was found that differences of 10^{-10} sec or less could be resolved.

The circuit was used in a study of the half-life of positrons in condensed materials. Half-life differences of the order of 10^{-10} sec were found in different absorbers; such differences appear to be caused by different annihilation times connected with the distribution of electrons within the absorbers.

The same circuit, with the addition of differential pulse-height selectors, was used in a triple-coincidence study of the fine structure and alpha-gamma angular correlation from Po^{210}. The results indicate that the gamma rays of this body are of electric quadrupole.

Third Session Discussions

"Differential coincidence counting method," by Z. Bay, R. R. Meijer, and G. Papp, George Washington University, Washington, D. C. In the usual method of coincidence counting, if two pulses overlap to some extent they are considered to be in coincidence. By using an anticoincidence circuit in conjunction with a coincidence circuit, it is possible to eliminate pulses that merely overlap to some extent, and count as coincidences only those pulses that exactly coincide in time.

The circuit used is shown in Fig. 9. The block diagram in Fig. 10 shows how the outputs from this fast circuit are fed into a slow coincidence circuit and then to two scalers, one of which records all coincidences and the other those remaining after selection.

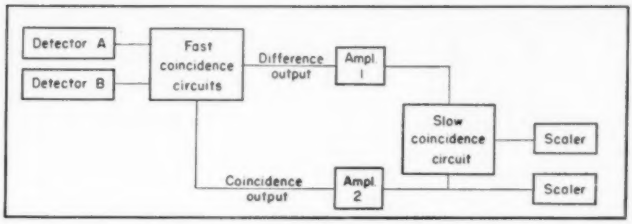

FIG. 10. Differential coincidence-counting circuit (Bay, Meijer, and Papp)

This circuit improves the resolving time by an order of magnitude. No true coincidences are lost. Experiments show that the dependence of resolving time on the pulse period of scintillation pulses is negligible, and essentially the dependence on the random delays of the counters remains.

"Time resolution of scintillation counters," by G. A. Morton, RCA Laboratories Division, Princeton, N. J. Both the phosphor and the photomultiplier contribute to the time error in scintillation-counter measurements. The two factors determining the behavior of the phosphor are the total useful light output and the decay constant of the phosphor. The transit time spread of electrons through the photomultiplier and the statistical fluctuations in pulse height both cause a time error in this element.

A reasonable value for the root-mean-square time spread in a typical photomultiplier is 0.5 mμsec per stage. The assumption of a Gaussian time distribution is not too unrealistic.

The time error of a scintillation is a function of the fraction n/N_e of the total charge N_e released by the scintillation from the photocathode, where n is the number of electrons required to trigger the photomultiplier. Minimizing the expression for the root-mean-square deviation in time t, with respect to n, then $t_{rms} = \alpha\beta A/N_e$ and $n_{opt} = N_e\beta/\alpha B$, where α is the phosphor time constant, β the rms time spread per stage in the multiplier, and A and B are constants related to statistics of the multiplier and have a value of the order of unity.

Evaluating the expression for the time error, the values given in Table 2 are obtained. The limit of photomultiplier resolution, using a stilbene crystal with $n = 1$, is found to be $t_{rms} = 4 \times 10^{-11}$ sec. If the results reported by Law hold for the dynode materials used in photomultipliers, this value cannot be realized.

"Resolving time of scintillation counters," by R. F. Post, University of California Radiation Laboratory, Berkeley, Calif. The expressions given by Morton in the preceding discussion have been obtained in another form, and have been extended to include the light collection time. For an idealized case, it can be shown that

$$(\Delta t)^2 = \frac{Q}{R^2\lambda^2}\left[1 + \frac{2(Q+1)}{R}\right]$$

where Δt corresponds to t_{rms}. Q corresponds to n, λ is the decay constant of the scintillator, and R is the maximum value of the number of electrons expressed as a function of time. However, in this equation the effect of light collection time has not been considered. If the time required for the scintillation light to reach the photocathode is considered, it is found that statistical fluctuations double the resolving time in a light pipe 2-in. long.

"Time statistics of scintillation photons," by D. C. Moore, University of Nebraska, Lincoln, Nebraska. Using a positron source with two crystals as shown in Fig. 11, a larger smear than was expected was obtained in delayed-coincidence counting of the $\frac{1}{2}$-Mev annihilation radiation, as shown in Fig. 12. A photomultiplier similar to the RCA 4646 obtained from the Technical Institute, Zurich, Switzer-

TABLE 2—Time Errors in Photomultipliers as Computed by Morton

Phosphor	N_e *(electrons)*	α *(sec)*	n_{opt} *(electrons)*	t_{rms} *(sec)*
Liquid	100	3×10^{-9}	27	2.5×10^{-10}
Stilbene	300	6×10^{-9}	40	2.0×10^{-10}
Anthracene	500	3.6×10^{-8}	11	3.8×10^{-10}

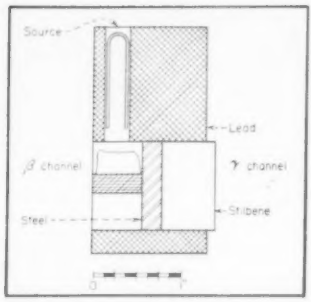

FIG. 11. Positron source and crystal arrangement for delayed coincidence counting (Moore)

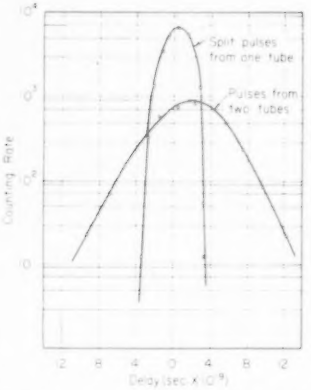

FIG. 12. Results obtained with source shown in Fig. 11 (Moore)

land, was used. This tube gave a 4-volt output pulse from the first electron.

These results confirm the statistical analysis of Post. When the optical coupling was improved, better resolution was obtained.

Fourth Session Papers

"Performance of pulsed photomultipliers," by R. F. Post, University of California Radiation Laboratory, Berkeley, Calif. Pulsed operation can sometimes be used to obtain maximum gain, output current, and speed of response with a photomultiplier. It tends to minimize noise and breakdown associated with ionization phenomena that limit d-c operation.

The optimum operating voltage (about 4 kv for a 1P21) can only be attained if the pulsing time is shortened to 1 or 2 μsec, and if the pulse repetition rate is not made too high. However, some tubes cannot be pulsed at appreciably elevated voltages even if the pulsing time is very short; this is attributed to differences in residual gas pressure and field emission phenomena between tubes.

Using 931A and 1P21 photomultipliers under pulsed conditions, the gains were about 10^9, enabling direct display of noise counts on a fast oscilloscope using a K-103 cathode-ray tube. The noise output pulses from single electrons at the photocathode had a width of 10^{-9} sec or less. Considering broadening of the pulse by the transit time in the oscilloscope, RC charging in the cables, and dispersion in the RG7U line used, a pulse width of 0.8×10^{-9} sec at half maximum is calculated for the pulse at the base of the photomultiplier. The original pulse can be calculated as 0.5×10^{-9} sec, and, therefore, the decay time for the anode surfaces cannot be longer than 7×10^{-11} sec. This disagrees with the results obtained by Dr. Law, which were obtained for steady-state conditions and different dynode surfaces.

"High-speed oscilloscope," by C. H. Smith, Naval Research Laboratory, Washington, D. C. A travelling-wave cathode-ray tube is used in an oscilloscope that provides a writing speed in excess of 10^{11} trace widths per sec, deflection factors of 0.6 volt per trace width vertical and 1.0 volt horizontal, at least 90 db isolation between deflection axes, transit-time distortion of 2×10^{-10} sec, and a total field of at least 100 trace widths horizontally and 125 vertically.

The travelling-wave deflector consists of a distributed-helix transmission line of 50 ohms impedance. The circumference of the helix is adjusted so that the phase velocity of the signals along the axis of the helix equals the beam velocity. The equivalent transit time of the deflector is then equal to the transit time under one turn of the helix.

A 2.5×3.0-cm luminescent screen is used to display traces.

"Pulse-amplitude analyzers for spectrometry," by G. G. Kelley, Oak Ridge National Laboratory, Oak Ridge, Tenn. For uniform smearing of the channels of a pulse-height analyzer, the width of these channels should be proportional to the square root of the pulse amplitude, but convenience usually dictates a constant width. About 3 volts is the minimum acceptable channel width, and if there are three or four widths over a peak in pulse heights, the distortion will not be objectionable.

At ORNL, a type 404A tube is used to achieve the best trigger response uniformity for various channel widths in pulse discrimination. Stability and speed are of prime importance in discriminator circuits. Pulse lengthening diodes lessen the speed and give large backcurrents. Therefore, germanium diodes are used in the ORNL 20-channel analyzer to give pulse lengthening and still achieve good response.

Gating of the signal channel in a pulse-height analyzer should be avoided. An inspection circuit that accomplishes the same purpose without gating the signal channel has been used in the 20-channel analyzer.

"An analysis of new electronics required for optimum use of scintillation counters," by W. A. Higinbotham, Brookhaven National Laboratory, Upton, N. Y. Improved auxiliary equipment is needed for use with scintillation counters. Since the gain of a photomultiplier is approximately equal to the seventh power of the high voltage applied to the dynodes (for a 5819 tube), power supplies with good stability are required.

Amplifiers that have a linear response that can be calibrated and that recover quickly from overloads are also needed. Secondary-emission multiplier amplifier tubes, such as those discussed by F. Wells, should be of use.

A convenient method of pulse-height analysis is to use a cathode-ray tube and photograph the screen. A gray wedge and lengthened pulses would give a more easily read record. Also, the oscilloscope would have to be modified so that the intensity of the trace would be independent of the repetition rate.

Fourth Session Discussions

"Artificial coincidence with a single photomultiplier for suppressing dark-current pulses," by Z. Bay and W. A. Tanner, George Washington University, Washington, D. C. By using a delayed coincidence circuit with one photomultiplier, only scintillation pulses appear at the coincidence output when the delay is longer than the

period of dark-current pulses and less than the phosphor decay time. For a two-electron case, there is a 50% probability of getting a coincidence with two photomultipliers; with the one-tube coincidence arrangement, the probability is 96%.

The method is limited by the gain of the tube and the sensitivity to the coincidence circuit. The present sensitivity of the coincidence circuit is $\frac{1}{2}$ volt. To achieve the highest gain for 2-electron coincidences, the gain of the photomultiplier must be about 2×10^7.

Preliminary experiments show that the method is practicable.

"Chronotron timing system," by J. W. Keuffel, Princeton University, Princeton, N. J. A timing system for the measurement of μ-meson lifetimes in the millimicrosecond range has been in operation for a year. Pulses from large liquid scintillation counters go through distributed amplifiers to a pulse-forming circuit and then into a chronotron timing circuit that has been described in *Rev. Sci. Instr.* **20,** 197 (1949).

The timing circuit provides 16 channels, each 16 mμsec wide. During the time this circuit has been in operation, the channel widths have shown a stability of 1 mμsec. The over-all time precision including lags for fast pulses through the liquid scintillators, is 1–2 mμsec.

"Pulse equalizing in a coincidence circuit," by B. Smaller, Argonne National Laboratory, Chicago, Ill. In coincidence counting, a difference in pulse heights is a disadvantage. With two coincidence pulses of different heights, the threshold level is reached at a different time for each pulse, giving a jitter effect. This is usually overcome by amplifying the small pulse, thus equalizing the slopes of the pulses. However, it is simpler to reduce the height of the larger pulse and equalize their peaks.

A circuit to accomplish this by using a variable bias that depends on the height of the pulse has been built. A block diagram is shown in Fig. 13.

"Some British scintillation counters," by R. Y. Parry, E. K. Cole, Ltd., London, England. This British company has developed a laboratory scintillation counter and a medical probe-type scintillation counter that is used in I^{131} studies.

The laboratory counter uses an EMI 5311 photomultiplier. The scintillation crystal is contained in a light-tight drawer above a sample chamber. The entire assembly is shielded with 5 cm of lead. A counting rate double background can be obtained with 2×10^{-8} curies of Co^{60}.

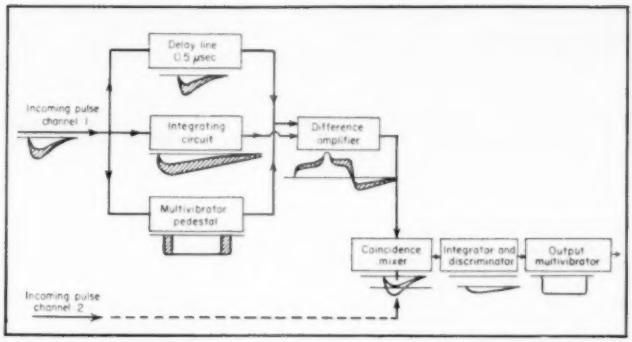

FIG. 13. Pulse-equalizing coincidence circuit showing waveforms obtained (Smaller)

The medical counter uses an EMI 5659 photomultiplier with a crystal sealed in Lucite. Also incorporated into the scintillation head is a feed-back amplifier with three gain settings. A lead collimator is used to give a directional characteristic for tumor localization; a geometry of 10^{-5} is achieved. With the collimator removed, 600–700 cpm are obtained from a thyroid one hour after 1 μc dose of I^{131} is administered. At that time, it is calculated that 40% of the iodine has been taken up by the thyroid.

"High-energy gamma-ray spectrometer," by M. R. Cleland and H. W. Koch, National Bureau of Standards, Washington, D. C. With high-energy gamma rays, the range of the secondaries produced in NaI is of the order of centimeters, and with a small crystal, an energy loss occurs. To eliminate this loss in a high-energy spectrometer, a 4-ft long tank of terphenyl in xylene is used, taking advantage of the fact that most of the secondaries are produced in the forward direction. This tank is scanned by 16 selected 5819 photomultipliers. The outputs of the tubes are connected in parallel with decoupling resistors, giving an output integrated over all the tubes. A variable resistor is used to adjust the dynode voltages of each tube so that all tubes give approximately the same pulse height.

The energy resolution is limited by the variation of light collection efficiency throughout the liquid. This variation was about $\pm 10\%$.

Monte Carlo statistics used to estimate distribution and energy range indicate that the apparatus will collect 95% of the energy from 35-Mev gamma rays, but at 5 Mev the apparatus will malfunction. Bremsstrahlung spectra determined with the betatron operating between 25 and 44 Mev are in agreement within the energy resolution with a corrected theoretical distribution.

CORRECTION. . . . .

In the letter "Binary vs Decade Scalers" by R. R. Newell, in the February, 1952, issue, the equation at the top of page 83 should read

$$\sigma_{net} = \sqrt{\sigma^2_{gross} + \sigma^2_{background}}$$

In the third column of page 82, the value given as 10m should be 10M.

Room-Protection Measurements for Cobalt-60 Teletherapy Units

When gamma rays are used for therapy, care must be taken to protect personnel working in the area. From the data given here, wall thicknesses sufficient to give proper protection can be calculated

By W. R. DIXON, C. GARRETT, and A. MORRISON
Radiology Laboratory, Division of Physics
National Research Council, Ottawa, Canada

THE WALLS, FLOOR, and ceiling of a treatment room in which a Co^{60} teletherapy unit is used must be thick enough to reduce the gamma-ray intensity outside the room to the tolerance level. While the main features of room protection problems are common to all beam therapy installations, it seems that the protection problem becomes more important as the conditions for teletherapy are better achieved.

To deliver a dose to internal tumors which is high compared to the dose delivered to the intervening tissue, it is necessary to use a strong source of penetrating radiation at a distance from the patient. A successful combination of these factors has the concomitant result that walls of a considerable thickness are required to protect personnel working in the area. Room protection for teletherapy units may then become a matter of some economic importance.

The protection problem may be considered in two main aspects: protection against the direct beam, and protection against scattered radiation. Usually the beam direction is restricted to travel in a vertical plane, so that the major part of the protection design is concerned with the scattered radiation. For a Co^{60} source, the energy of this radiation is in the range 200–1,200 kv, depending on the angle of scatter.

Experimental measurements have been made of the attenuation of the direct beam in concrete and lead, of the intensity of radiation scattered from a phantom and a wall, and of the attenuation of the scattered radiation in concrete and lead for various angles of scatter. These measurements were made with a Co^{60} source with an output of 22 r/min at one meter.

Direct Beam

To specify the protection for the direct beam, one requires a knowledge of the gamma-ray intensity, the maximum beam size at the wall or floor in question, and the attenuation of the radiation in the protective material.

Intensity and beam size. The gamma-ray intensity is found to vary with distance approximately according to the inverse square law, so that it is sufficient, for protection purposes, to measure the output at one distance, say at 2 meters.

The beam size at any distance can be calculated as if there were a point source. However, there are several effects which cause a "smearing out" of the edges of the beam. These are (1) the extended source, radiating through a defining aperture, gives rise to a geometrical penumbra; (2) the sides of the defining diaphragm scatter gamma radiation in all directions; and (3) the diaphragm transmits a certain percentage of the incident radiation.

An example of the type of beam profile to be expected is shown in Fig. 1 as a plot on semilogarithmic paper. The arrangement of the defining diaphragm used for these measurements is shown in Fig. 2; the phantom shown in Fig. 2 is not in place.

Absorption in concrete and lead. The attenuation of the direct beam through protective materials such as concrete and lead can be determined only by experimental measurements, since it is necessary to know the transmission in broad-beam conditions.

The transmitted beam may be thought of as consisting of a direct component, and softer components which arise from scattering in the absorbing medium. These softer components become relatively more important as the absorber thickness is increased. For a given thickness,

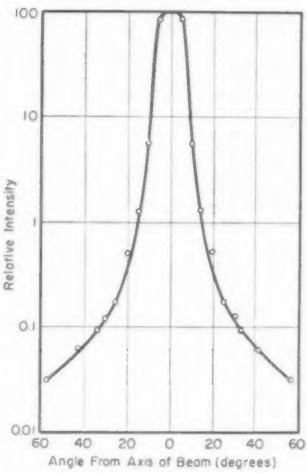

FIG. 1. Intensity profile of beam at 3 meters for a half-angle of 7½°. Origin of coordinates is at the source

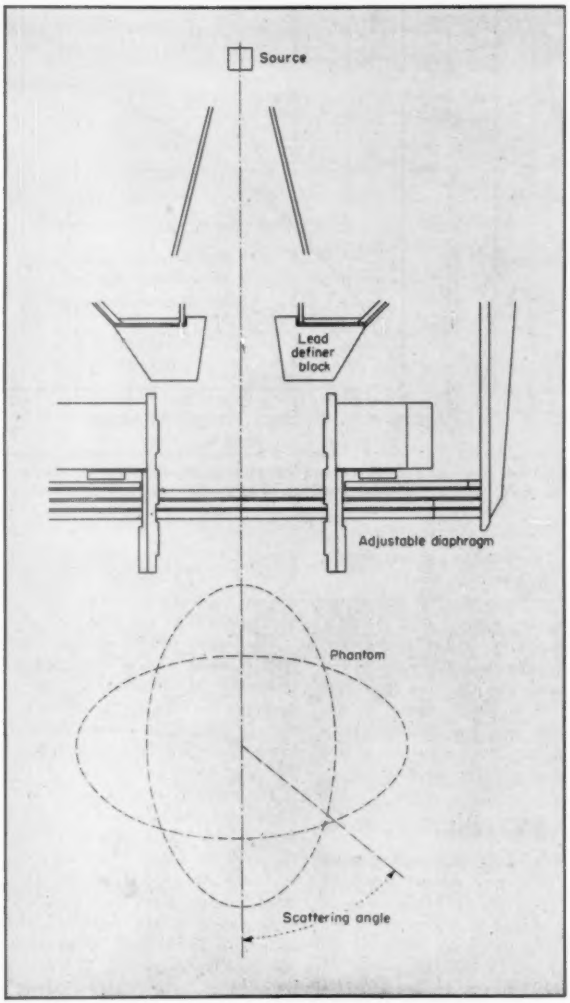

FIG. 2. Beam definition system used for the experimental measurements

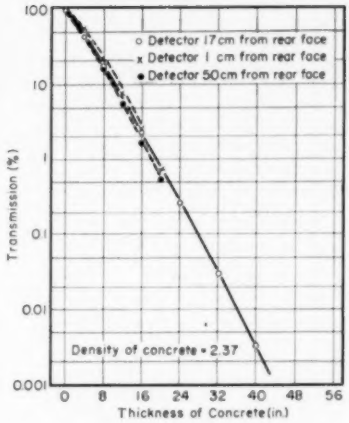
Detector 17 cm from rear face
Detector 1 cm from rear face
Detector 50 cm from rear face
Transmission (%)
Density of concrete = 2.37
Thickness of Concrete (in.)

FIG. 3. Broad-beam absorption of Co^{60} gamma rays in concrete

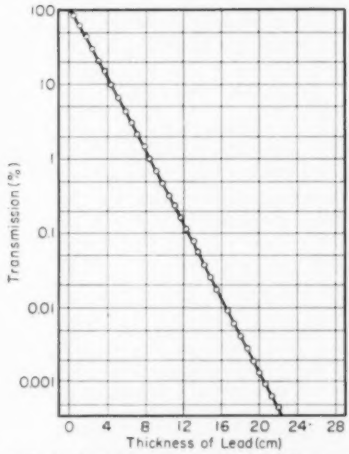

FIG. 4. Broad-beam absorption of Co^{60} gamma rays in lead

their intensity increases with increasing field size, so that measurements should be made with the largest field to be used clinically.

The results of our measurements are shown in Figs. 3 and 4. The broad-beam transmission of Co^{60} gamma rays has been measured through 40 in. of concrete and through 22 cm of lead, with corresponding attenuations of 3×10^{-5} and 5×10^{-6}, respectively. For these low values of the transmitted intensity, it was necessary to shield the detector against the general room level of scattered radiation. But of course this had to be done in such a way that gamma radiation scattered from a large area of the absorbing material was detected. A further complication is introduced if there is an appreciable percentage of backscatter of the transmitted beam from shielding material behind the detector. Since the spectral distribution of the transmitted beam, and consequently the percentage of backscatter, depend on the absorber thickness, an appreciable error could be introduced. Measures were taken to minimize this effect.

For the concrete transmission, a 5×5-ft barrier was used. The detector was located at a horizontal distance of 3 meters from the source, and a fixed distance of 17 cm from the rear face of the barrier. A circular field of diameter about 130 cm, at the detector, was used. Without the barrier, the measured intensity was 2.3 r/min. A variety of air-wall ioniza-

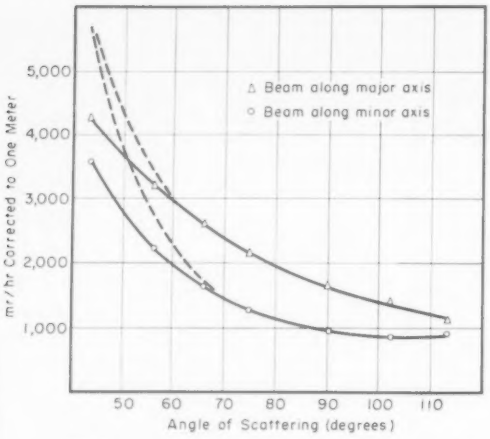

FIG. 5. Angular distribution of gamma radiation scattered from phantom. Dashed curves are for case without diaphragm. Source output is 22 r/min; field size is 26 × 26 cm, at 1 meter

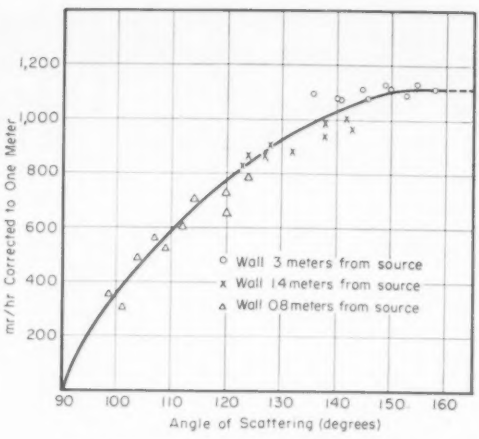

FIG. 6. Angular distribution of gamma radiation scattered from concrete wall that is placed normal to the beam. Source output is 22 r/min; field size is 26 × 26 cm, at 1 meter

tion chambers were used as detectors, with the chamber-wall thickness being great enough to establish electronic equilibrium and to exclude electrons that are ejected from the barrier.

The region behind the concrete barrier was shielded from general room scatter with large overlapping sheets of lead on 4 × 8-ft frames. For a thickness of 48 in. of concrete, the shielding was found to be insufficient, since the value of the transmission obtained was found to lie somewhat above the extrapolated curve of Fig. 3. The shielding did, however, reduce the measured intensity for 48 in. by a factor of 13. The detector was located near a 4 × 4-ft open window so that the effect of backscattering was negligible.

Previous results obtained by the present authors with a much weaker source (0.8 r/min at one meter) are shown as the dashed curves in Fig. 3. These curves show that the percentage transmission for the detector only 1 cm from the wall is higher, and that for the detector 50 cm away is smaller, than for the detector 17 cm away.

Measurements of the broad-beam transmission of Co^{60} gamma rays through 24 in. of concrete, made by Kennedy, Wyckoff and Snyder* are in good agreement with our results.

For lead transmission measurements, the beam was directed vertically downwards. The detector was located at a distance of 75 cm from the source, and about 9 cm from the rear side of the lead absorber sheets, with a 20 × 23-cm rectangular field at the detector. Lead shielding was provided on all sides. Lead was also used under the detector since the intensity of the backscatter from lead is appreciably less than that from materials of low atomic number. The results are shown in Fig. 4.

Scattered Radiation

The side walls and ceiling must provide protection against scattered gamma radiation that originates in the patient and in the parts of the walls or floor which are struck by the direct beam. It is convenient to consider that the scattered radiation in fact originates in virtual (anisotropic) sources, with their angular dependence being established by experimental measurements.

Intensity distribution from phantom. The intensity distribution of the gamma radiation scattered from a masonite phantom was measured; the results are shown in Fig. 5. The phantom was an elliptic cylinder with a 36-cm major axis and a 20-cm minor axis. The scattered radiation was measured with the beam directed along both the major and minor axes of the ellipse. A radiation survey meter, Beckman Model MX-2, was used. The beam was directed horizontally through a 4 × 4-ft open window, at a distance of 3.5 meters. Lead sheets $\frac{1}{16}$ in. thick were used to cover the area surrounding the open window.

The values plotted in Fig. 5 have been obtained from the measured intensities by multiplying by the square of the distance, in meters, from the phantom. The plotted values are averages of the results for distances of 1.5, 2, 2.5 and 3 meters.

The geometrical arrangement of the diaphragm and phantom is shown in Fig. 2, from which it is seen that in this case the beam is defined by the lead definer block. Gamma rays scattered from the block were absorbed to some extent in the material of the adjustable diaphragm. When the adjustable diaphragm (Fig. 2) is entirely removed, and the phantom is left in the same position, one obtains results of the type shown by the dashed curves in Fig. 5. These curves show that for scattering angles less than about 60°, the contribution from a defining diaphragm may be considerable, but that for scattering angles greater than 60° this contribution is small.

The output of the source used for these measurements was 22 r/min at 1 meter, and the field size at 1 meter was 26 × 26 cm. Since the scattered intensity is proportional to the output, and to the area of the field at a given distance, the results shown in Fig. 5 may be easily converted to other source strengths and field sizes.

* R. J. Kennedy, H. O. Wyckoff, W. A. Snyder, *J. Research Natl. Bur. Standards* **44**, 157 (1950)

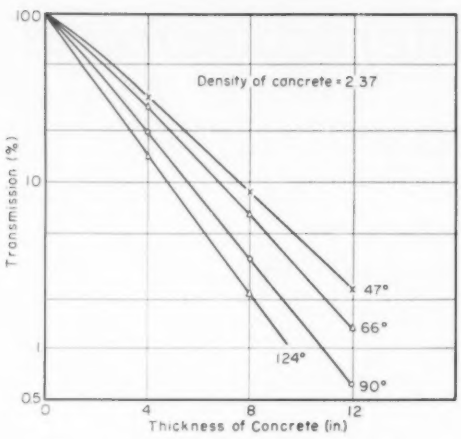

FIG. 7. Broad-beam absorption of scattered gamma radiation in concrete for various angles of scattering

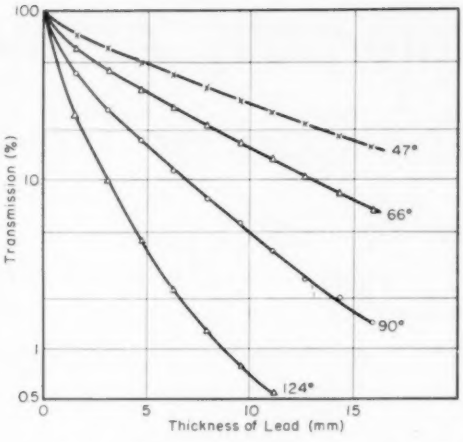

FIG. 8. Broad-beam absorption of scattered gamma radiation in lead for various angles of scattering

Intensity distribution from concrete wall. The intensity distribution of the gamma radiation scattered from a concrete wall 8 in. thick is shown in Fig. 6. The wall was placed normal to the beam at distances of 0.8, 1.4 and 3 meters from the source. The wall was placed at these various distances so that it would be possible to cover a wide range of scattering angles, and at the same time be possible to measure the intensity at points where the scattering from the defining diaphragm was small. The intensities of the scattered radiation have been measured at distances from the wall ranging from 1.5 to 4.5 meters, and the readings then converted by the inverse square law to a distance of 1 meter from the wall.

Absorption in concrete and lead. Experimental results for the absorption of the scattered radiation in concrete and lead, for various angles of scatter, are shown in Figs. 7 and 8. The transmitted intensity was measured with an ionization chamber and vibrating-reed electrometer. Shielding was provided around the detector against the general room level of scattered radiation. With the shielding arrangement used, the part of the absorber which could scatter photons into the detector was 9×9 in., at a distance of about 5 in. from the center of the ionization chamber.

The absorption curves for concrete show a concavity downwards which is typical of broad-beam measurements. The absorption curves for lead show a concavity upwards which is typical of measurements made with an X-ray beam consisting of a spectrum of energies up to a maximum value. The reason for this difference is that the absorption in lead is much more dependent on the photon energy than is the absorption in concrete; a spectrum of energies arises from multiple scattering and from single scatterings through a small range of angles.

Sample Calculations

Consider a source with an output of 30 r/min at 1 meter, located 3 meters from the front wall and 2 meters from the side wall of a treatment room. To find the thickness required in the front wall, suppose that the intensity at a distance of 4 meters must be attenuated to a tolerance level of 6.25 mr/hr, and hence by a factor of 18,000. The required thickness of concrete is 38 in. (Fig. 3), and of lead is 17.5 cm (Fig. 4).

The thickness required for the side walls should be calculated for a number of points. Consider for example a point 2.35 meters from the patient, and receiving radiation scattered through 90°. Assume the field size at one meter to be 26×26 cm. Then the intensity, from Fig. 5, is found to be 410 mr/hr. To attenuate this to 6.25 mr/hr (to 1.5%) requires 10 in. of concrete or 16 mm of lead (Figs. 7 and 8). It is found that the thickness required in the more forward positions of the side wall is as much as 12 in. of concrete.

For the backwall protection calculations, one should assume scattering through an angle not larger than 90°, to take into account the most unfavorable scattering conditions (beam directed vertically downwards). For the example given, about 10 in. of concrete is required.

In most cases the intensity of backscatter from the front wall or floor is much less than the intensity from the patient, and in many cases may be neglected altogether since the wall thickness required varies essentially as the logarithm of the intensity. If the backscatter from the wall or floor must be considered, it may be assumed that the intensity of the direct beam is reduced to approximately 40% due to absorption in the patient. The contribution from the wall may then be added to the contribution from the patient, and the required protection thickness calculated as if the total intensity originated in the patient. Since the contribution from the wall or floor is, on the whole, of a lower energy than the contribution from the patient, this procedure may result in slightly overestimating the thickness required.

* * *

The authors wish to acknowledge the cooperation of Eldorado Mining & Refining (1944) Ltd., Ottawa, in this project, and the permission to use the diagram shown in Fig. 2.

Internally Administered Isotopes for Cancer Therapy

Past predictions on the bright future of radioisotopes to treat cancer are reviewed in the light of five years' experience. They form the basis for this up-to-date report on what has been and is being done to advance the use of such therapy

By MARSHALL BRUCER
Chairman, Medical Division
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Oak Ridge, Tennessee

FIVE YEARS AGO, in the flush of enthusiasm over the future of the peacetime uses of atomic energy, many brash predictions were made of cancer cures with radioisotopes. To report to the scientific public the current status of radioisotope therapy and the extent to which isotopes have fulfilled their predicted value, the American Association for the Advancement of Science at the 1951 annual meeting arranged a Symposium on Cancer Therapy with Radioisotopes.

An attempt was made, in organizing the symposium, to present the total problem.

Thus the persons participating represented four types: those who have used the common isotopes, those who contemplate new usages, those active in the daily production of isotopes, and those responsible for the distribution of unforeseen quantities of these new materials to a medical profession largely unprepared to receive them.

The plan of the symposium was to discuss all internally administered isotopes in a morning session. An evening session reviewed and summarized the impression of the first five years' experience. The papers presented during these two sessions are abstracted here.

(An afternoon session was devoted to discussions on the use of large radioactive sources in teletherapy units, the most important of the externally administered isotope problems. This information will be published next month in NUCLEONICS.)

Status of Radiophosphorus in Cancer Therapy

By L. A. Erf
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Philadelphia, Pennsylvania

Radiophosphorus has been applied in many ways to the cancer problem. At present, P^{32} is used mainly as a detecting agent *for* cancer, or as a therapeutically destructive agent *of* cancer; but in the future it will be more widely used in determining the *cause* of cancer. It can be used *therapeutically* in cancer as follows:

1. P^{32}, in a sodium phosphate solution, can be applied to a piece of blotter that can be attached with adhesive tape to a skin cancer. This has and is being done with some success.

2. P^{32}, in a sodium phosphate solution, may be given orally or intravenously for treatment of leukemia, metastatic cancer, etc. While the results are not dramatically successful, P^{32} is equally as good as many methods of treating these diseases. It is the method of choice in treating polycythemia vera.

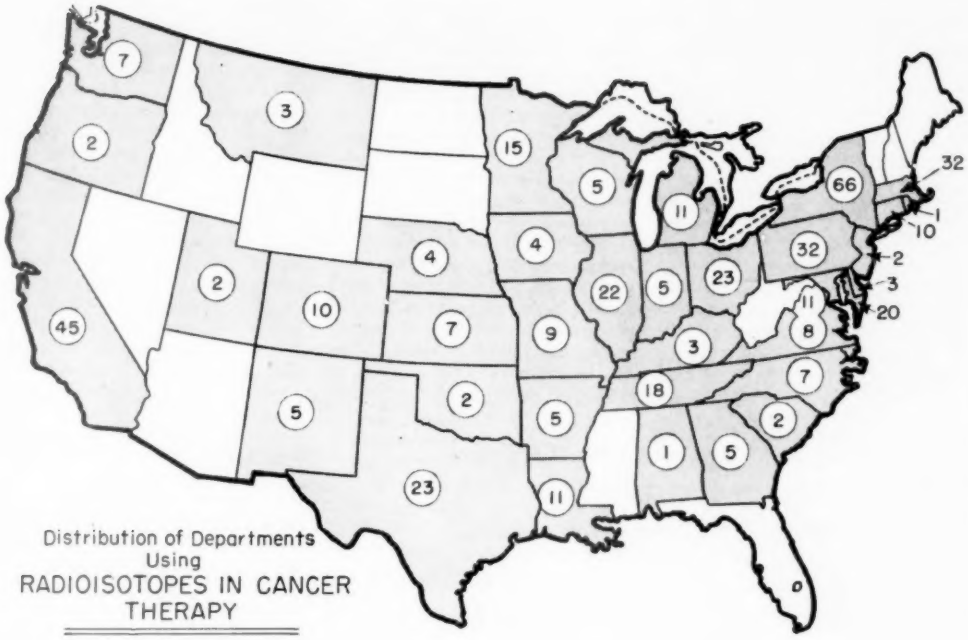
3. P^{32}, in a chromium phosphate suspension, can be injected interstitially into a cancer. The method is highly experimental but may have some theoretical advantages over radiogold.

4. P^{32} solutions can be placed in Lucite capsules that can be applied to malignant lesions of the cornea, sclera, or conjunctiva of the eyes. Radiostrontium has largely replaced P^{32} in this type of therapy but the original method employed P^{32}.

5. P^{32} can be instilled into rubber balloons that can be swallowed and lowered to various levels in the gastrointestinal tract or inserted into the rectum, vagina, or other orifices.

Hertz has recently shown that testosterone will increase the phosphorus metabolism of cancer cells about 15 times above their usual rate (normal cells, about 3 times). This differential uptake may be the forerunner of a technique in which agents are used that cause differential metabolic uptake of isotopes, thereby increasing the concentration of radiation within cancer cells.

The predominant future use of radiophosphorus lies in its ability to aid in the understanding of intracellular chemistry. Both X-rays and P^{32} slow mitosis in the stage of prophase, and Marshak has performed experiments that indicate that ionization apparently inhibits the conversion of the nuclear precursor into ribonucleic acid.



Distribution of Departments Using RADIOISOTOPES IN CANCER THERAPY

Total Departments-441

It probably will be this type of experiment with radioisotopes that will show how the intracellular enzymes, hormones, or nucleoproteins of cancer cells differ from normal cells.

Status of Radioiodine Therapy

By William H. Beierwaltes
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University Hospital
Ann Arbor, Michigan

This report summarizes five published papers and the experience of seven other clinics in the treatment of 205 cases of carcinoma of the thyroid with radioiodine, I^{131}. Biopsy or autopsy indicated carcinoma in all patients, and there was palpable, X-ray, or histologic evidence of extension or metastasis of the neoplasm outside the thyroid gland. They represented from 5% to 50%, averaging 33%, of the total number of patients with histologically proven carcinoma of the thyroid seen by these authors during the same period of time.

Basis for selection of patients. Of 205 patients, 201 had partial or total thyroidectomy. Since X-ray therapy has been an accepted adjunct to surgery in the treatment of thyroid cancer, over ¾ of these patients had X-ray treatment. In many of the others, the lesions were deemed too disseminated to treat with X-rays.

Cancer morphology. Cancerous thyroid must resemble normal thyroid if good results are to be achieved. In this series, 16 patients who responded "favorably" to I^{131} treatment had a follicular, 10 patients had an alveolar type, and 6 had papillary carcinoma. No patient with more undifferentiated carcinoma showed unequivocal improvement with I^{131} treatment.

Demonstrated ability of cancer to concentrate iodine. Slightly more than half of the authors used autoradiographic procedures to demonstrate concentration of iodine in the tumor. Those who did so, found no positive or negative correlation with the ultimate result of I^{131} treatment.

Most authors used external counting over an area of known metastasis and compared this count with that over a similar anatomic area. Relatively small metastases near the body surface showing an uptake count in 100 seconds that is greater than 15 times the count over a similar anatomic area, usually show retrogression on exposure to a treatment dose of I^{131}.

It is thought that one of the most accurate methods of predicting a good therapeutic response to I^{131} in a given patient with carcinoma of the thyroid is excretion of preferably less than 30% of a tracer or therapeutic dose of I^{131} in the first 48–96 hours after administration. This method of prediction is relatively inaccurate. Urinary iodine excretions were recorded in 5 patients who showed unequivocal decrease in size of bone or lung metastases or disappearance of cervical nodes after a single treatment dose. They showed excretion varying from 20% of the administered dose excreted in 96 hours to 79% in 72 hours.

The blood radioiodine level after a tracer or treatment dose has been used much like the urinary iodine excretion test. The unknown volume of functioning metastases and their rate of iodine turnover render this index less

valid. Only two patients who had an unequivocal decrease in size of metastases had blood levels recorded. These were recorded as 0.4 μc of I^{131} per gram of blood at 96 hours and 0.4% of the dose per kilogram of blood. Obviously, no conclusions can be drawn.

Methods of enhancing uptake. Thyroidectomy is thought to release the pituitary's production of thyroid-stimulating hormone so that the pituitary will stimulate functioning metastases to pick up I^{131}. The present review disclosed the fact that thyroidectomy rarely, if ever, converts a patient with no response to I^{131} treatment to one with an unequivocal response. Much the same can be said of thiouracil administration. Thyroid-stimulating hormone is at present commercially unavailable and has had inadequate study.

Dosage and hospitalization. The maximum single dose administered to an adult was 315 mc. The average single dose was 80 mc, and the largest total dose was 2,000 mc in 96 months. The maximum single dose administered to children 1–16 years of age was 264 mc, the average single dose 46.4 mc, and the largest total dose 230 mc in 24 months. No infants under one year of age were given a treatment dose of I^{131}. The longest period of hospitalization after a treatment dose was 40 days. One radiologist did not hospitalize his patients for treatment. The average period of hospitalization after a treatment dose was 4.7 days, exclusive of the one 40-day report.

Results of treatment. The most certain criterion of positive response to treatment would be the complete disappearance or unequivocal decrease in size of metastases in lung, bone, or cervical nodes. Four patients were reported to show complete disappearance of one or more metastases in the lung. No bone metastases completely disappeared. Eight patients showed unequivocal decrease in size of one or more lung metastases. Two showed by palpation complete disappearance of cervical node enlargement, three probably complete disappearance. Three patients were thought to have a "complete cure" and have remained so for periods of follow-up of 11, 19, and 4 months. The first patient had lung metastasis, and the second two patients had only palpable cervical node involvement at the beginning of treatment. Re-biopsy of the metastasis after treatment showed retrogressive changes compatible with radiation damage in several patients, increased differentiation of the remaining neoplasm in at least two patients, but no reports of decreased differentiation.

Sixteen patients, or 8% of the 205 patients treated, showed unequivocal improvement as a result of treatment, and three patients, or 1.5%, were thought to be "completely cured." It is concluded that radioiodine treatment of thyroid cancer is a useful adjunct in the treatment of an occasional selected patient with thyroid cancer who cannot be aided further by the well-established and effective methods of surgery and X-ray therapy.

Status of Radiogold Therapy

By Gould A. Andrews
Chief Clinician, Medical Division
Oak Ridge Institute of Nuclear Studies
Oak Ridge, Tennessee

Radioactive colloidal gold is being studied in several medical centers in this country; this report summarizes the work of a large number of investigators. The possible uses of this isotope fall into three general categories depending upon the route of administration.

1. Interstitial injection. The radiogold colloid can be injected directly into a tumor. It usually stays in or near the site of injection and only a small amount is carried by the lymphatics and blood stream to the liver and spleen. Such treatment is still experimental and the extent of its value is unknown.

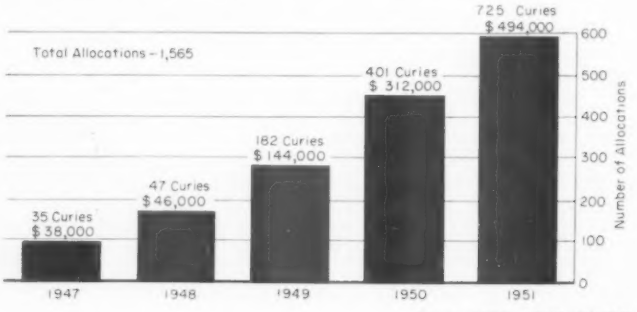
There are certain theoretical advantages to this type of therapy. By avoiding radiation of normal tissues, it is conceivable that relatively radioresistant localized tumors might be so treated. It is also possible to inject the gold under direct visualization by means of endoscopic instruments into regions not easily accessible. Finally, the gold may travel to some extent to regional lymph nodes and here offer a method of selectively radiating the areas of potential tumor spread.

There are certain obvious disadvantages to the direct injection of tumors. The most important is that no technique has been developed that makes possible a reasonably uniform distribution of the radioactive material in the tumor. To be effective, the treatment often depends upon unobtainable knowledge of the extent of the tumor. In some situations, there may be excessive irradiation of normal tissues either from the radiogold that is picked up in the blood and lymphatic channels and carried to the reticuloendothelial system, or from the gamma emission of the gold in the tumor itself. Furthermore, the injection process itself may be hazardous to the individual performing it.

A relatively new variation of the direct tumor-injection technique has been described for treatment of carcinoma of the cervix of the uterus. It has been found that by injecting the

RADIOISOTOPES IN

Allocations by Fiscal Year August 2, 1946–June 30, 1951



gold into the soft tissues adjacent to the uterus it is possible to obtain a high radiation dosage to the areas of most likely spread of the tumor.

Another similar use is in carcinoma of the prostate. In a group of patients who have tumors too extensive for surgical removal, treatment by direct injection of the lesion with radiogold is said to offer promise of good palliative results.

2. Intracavitary injection. There is a significantly large group of patients who have metastatic tumors involving a serous surface (pleura or peritoneum) and causing rapid formation of fluid. These patients often suffer more from the fluid and the inconvenience of having it repeatedly removed than they do from any other manifestations of the malignant disease.

When radiogold is given intrapleurally or intraperitoneally, a large amount of it deposits on the serous surface, and a small amount is picked up in the regional lymph nodes. A still smaller amount is carried to the liver and spleen. As a first result, a change often appears in the character of the fluid from bloody to clear. There may then be a disappearance of tumor cells. Finally, in a significant number of patients, there is a cessation of formation of the fluid.

The exact mode of action of colloidal gold when used in this way is not clearly understood. A fibrous thickening of the serous surfaces is sometimes noticed. This may be due to the radioactive gold. It is not felt that this treatment is likely to prolong life to any great extent, but it adds considerably to the comfort of the patients and is believed superior to X-ray therapy.

3. Intravenous injection. When given intravenously, radiogold is removed from the blood by the liver, spleen, and to some extent by the bone marrow. There is no evidence of a high concentration in lymph nodes. This form of treatment can be used for patients who have chronic lymphocytic and chronic myelocytic leukemia. The results are similar to those obtained with other standard forms of therapy.

Radioactive gold is one of the simplest methods of treatment from the patient's point of view, since it can be given with relatively little hospitalization. However, it is considerably more hazardous to administer than radiophosphorus. One possible advantage of gold over phosphorus is the fact that with the gold the excreta are not highly radioactive and do not present a health-physics problem.

Problems with Newer Isotopes Being Investigated

By H. D. Bruner
Chief Scientist, Medical Division
Oak Ridge Institute of Nuclear Studies
Oak Ridge, Tennessee

The prime requirement for therapeutic use of internally administered isotopes is that they may be localized in or around the neoplastic tissue which is to be irradiated to the point of destruction. This assumes that the neoplastic tissue is more radiosensitive than normal tissue and/or that intensity of radiation per unit volume is greater for tumor than for normal tissues.

If the isotope segregates more or less evenly throughout the tumor, the ideal radiation on decay would be a negative electron with an average range in tissue of about 2.0 mm or about 1.8 Mev maximum energy. Gamma radiation with its low specific ionization and long range contributes a large fraction of the total body dose; in so doing the differential radiation dose to the tumor is reduced. It is not sufficient that the isotope be more concentrated chemically in the tumor; the radiation effects must also be localized differentially to the tumors.

Localization of the isotope must occur rapidly, particularly where short-lived isotopes are being used. For example, if the differential concentration begins to show up after one half-life has passed, roughly 70% of the total potential radiation has already been expended as whole-body radiation.

Similarly the per cent retention of a dose should approach 100%. If only a small fraction of a dose is retained, the entire body receives whole-body radiation during the 24 or more hours required for excretion. The net effect is to dilute an otherwise acceptable differential localization to the point of making it negligible.

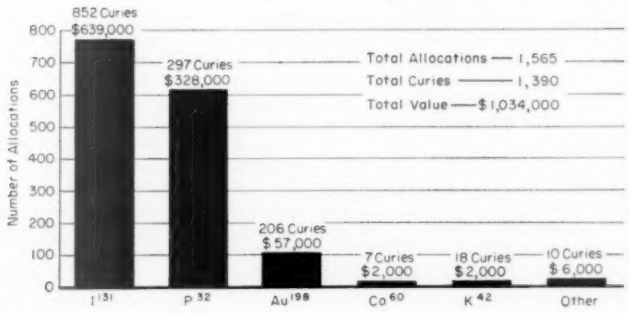
The desirable requirements for a therapeutically useful isotope should include a 100-fold differential concentration in the tumor; the concentration should take place promptly with a minimal loss due to excretion, and the isotope should decay by alpha- or beta-particle emission, *K*-capture X-rays, or internally converted X-rays.

Examples of work in progress. Astatine-211 appears to behave as a halogen, and biologically to follow the distribution of iodine, particularly into the thyroid. It has, in fact, been recovered from the thyroglobulin isolated from treated animals and been used in a limited number of persons with encouraging results. The 5.9-Mev alpha particle and the *K*-capture X-ray make for well-localized tissue destruction, but because At^{211} must be produced by an accelerator and has a 7.5-hour half-life, it is not widely available.

Another line of study is based on the distribution of materials according

CANCER THERAPY

August 2, 1946–June 30, 1951 **Allocations by Isotope**



to physical size of the particles. Very large particles of charcoal, 30 to 60 microns in diameter, with radiogold (Au^{198}) fixed on their surfaces were injected intravenously by Mueller of Switzerland. They acted as micro-emboli and plugged many of the arterioles and capillaries of the lung, with the result that the lungs were exposed to a more or less even field of radiation. By introducing a heart catheter into the pulmonary artery of a particular lobe, it should be possible to embolize just one lobe and still further localize the radiation. A similar coating of gold on silver has been reported.

Au^{198} colloids are quite inert and are not transported by the lymphatics. Silver, on the other hand, is mobilized, but does not have a really good radioisotope. By coating the surfaces of the gold colloid with silver, one can obtain the biologic characteristics of Ag and the radiation characteristics of Au^{198}. Several other colloids have been reported: $Mn^{52-54}O_2$, $Cr^{51}PO_4$, $CrP^{32}O_4$ and $Zn^{65}S$ pectinate. Although these are available for work on the particle-size problem, nothing definitive has resulted.

In our own laboratories, we have used gallium-72 against primary and metastatic osteogenic sarcomata. The results of 16 months intensive study are essentially negative, partly because presently available Ga^{72} has too much metal per unit of radioactivity so that metal poisoning supervenes, and partly because the gamma emission gives rise to a disproportionate amount of whole-body radiation. Accordingly, we have turned to research with another gallium isotope, Ga^{67}, which it is hoped will retain the bone-seeking property of the element. It has a more desirable radiation spectrum, longer half-life, and can be produced carrier-free.

Extent of Radioisotope Utilization in Cancer Therapy

By S. Allan Lough
Assistant Chief, Isotopes Division
U. S. Atomic Energy Commission
Oak Ridge, Tennessee

In 1947, 89 radioisotope allocations were made; in 1951 there were 594. These and other statistics on radioisotopes for cancer therapy are shown in the two graphs on pages 48 and 49.

> The enthusiasm for using radioisotopes internally in the treatment of cancer has not died. We have been through many heartbreaks during the past five years, but one of the sources of enthusiasm is our desperation with certain types of cancer. Fifty-five years of radiation treatment of cancer has produced positive results to which all scientists point with pride—yet we feel that we have only "almost" accomplished something. Although we are proud of what has been done with radioiodine, radiophosphorus, and colloidal radiogold, the initial treatment of choice is usually some other radiation method. Long-term evaluation is essential. It took 25 years to learn standard radiation methods. We need more time.
>
> —*Richard Chamberlain, M.D., University of Pennsylvania in AAAS Symposium discussion, December 28, 1951*

The number of allocations is increasing linearly and shows no sign of reaching a plateau. After 1948 there was a sharp upswing in use. This was attributable to the inauguration of the Atomic Energy Commission's program of distributing radioisotopes free for cancer research. The continued increase is due to participation by more physicians.

The number of departments using isotopes in cancer therapy has shown a slow but steady increase. See map on page 47. From 47 in 1947, the number has grown to 441 departments in 1951. In each year, almost every department engaged in this work used I^{131}, or P^{32}, or both. In 1951, Au^{198} was used in 47 departments, and is growing in popularity.

Development of Medical Use of Radioisotopes

By Paul C. Aebersold
Chief, Isotopes Division
U. S. Atomic Energy Commission
Oak Ridge, Tennessee

The medical use of radioisotopes from 1900 to 1946 was primarily limited by the lack of techniques and availability of the right kind of radiomaterials in sufficient quantities. Take, for example, the case of radium.

Although Danlos published his first case notes in 1904, radium therapy was considered inefficient until Dominice reported his work on filtered radiations four years later. Subsequent developments contributing appreciably to the therapeutic use of radium and its products included Failla's success in 1920 in enclosing radon in glass tubing of such size that it could be permanently implanted into tissues; Failla's later success in 1926 in enclosing radon in gold capillary tubing for similar use; and Paterson and Parker's success in 1934–38 in solving the problem of effecting homogeneous irradiation in practical radium therapy when multiple or relatively large sources of radiation are used at short distances.

Development of the medical use of radioisotopes may be even slower because the investigator must now be concerned not only with the physical characteristics of the radiomaterial but with its biochemical characteristics.

The Atomic Energy Act of 1946 directs the AEC to make radioisotopes available in a manner which will assure their safe use. To insure this provision, AEC has established certain criteria for the allocation of radioisotopes. It has also procured the services of an Advisory Committee on Isotope Distribution to assist in the formulation and operation of procurement procedures.

A subcommittee on human applications reviews all radioisotope requests proposing use of radiomaterials in humans. Regarding distribution, its aims are: (1) to make radioisotopes available for approved clinical investigations and for diagnostic and therapeutic purposes where they are needed and can be handled properly and safely; (2) to protect, as far as possible, patients from indiscriminate use of radioisotopes; and (3) to insure that adequate facilities are available to those planning to use the material.

In its continuing efforts to lessen the controls on distribution commensurate with public health and safety and to localize responsibility for health safety, the Commission this year published a code of Federal

Regulations to govern the procurement, delivery, possession, use, transfer, and disposal of radioisotopes.

It is also AEC's intent to publish health and safety standards at a later date for incorporation into these regulations.

Another step taken recently by AEC was the issuance of general authorizations. General authorizations make it possible for qualified applicants to obtain from any supplier any available form and quantity of any radioisotope, except tritium, obtainable under the Commission's distribution program without submitting numerous applications. Although general authorizations have thus far been issued only to institutions desiring the radiomaterials for research and development activities, the Commission is currently looking into the possibility of extending their scope for certain medical applications.

With the exception of occasional symposiums and lecture courses, the only opportunity for learning the techniques employed in the clinical use of radioisotopes has been by participating in an active clinical program. That this method of training has been quite successful is evidenced by the fact that within the past five years the number of institutions using radioisotopes in clinical studies has increased by 600%. Since the start of the Commission's distribution program, more than 1,150 papers have appeared in the scientific literature dealing with the use of radioisotopes in medical research, diagnosis or therapy.

Physicians' Responsibilities in Human Application

By Albert H. Holland
Medical Director, The Armour Laboratories, Chicago, Illinois, and Chairman, Subcommittee on Human Applications, U. S. Atomic Energy Commission

Fundamentally, the responsibilities (intellectual, social, moral, legal and professional) inherent in the use of radioactivity by a physician should not be greater than with other therapeutic agents since in every instance human life and health are involved. However, there is at least one cardinal difference, the factor of time. There are very few pharmaceuticals in common use today that are capable of causing severe side effects several years after discontinuation of therapy. Such is the case with many radioisotopes.

There is much yet to be learned concerning the ultimate biologic effects of radiation. Not only do we not understand the complex biochemical changes occurring during the acute phase of radiation damage, but we also have a limited knowledge concerning genetic effects of whole-body radiation.

The introduction of radioisotopes into the body is for all practical purposes irreversible, and once administered cannot be withdrawn or counteracted. There is no justification for empirical therapy with radioisotopes. This is one of the basic reasons for the requirement for local institutional radioisotope committees. It is essential that a group of men representing such disciplines as pathology, radiology, and internal medicine bring to bear their combined judgment on any given case.

Many of the elements now available in radioactive form have not been previously used in the practice of medicine since their stable isotopes had little therapeutic benefit. However, radioisotopes of certain of these elements have extremely desirable radiation characteristics which, if coupled with a favorable metabolic pattern, permit their effective use in medicine. Thus the physician and medical investigator are confronted with a whole new series of potentially effective therapeutic agents with which they have had little, if any, prior experience. Each of these isotopic agents must be carefully studied by the physicist and the chemist to determine their various characteristics. The biological and medical investigators must then do the necessary screening work in animals to provide sufficient data for consideration for human use.

Safe, intelligent use of radioactive materials can only be achieved if the physician devotes the required time and study to obtain adequate training, experience, and knowledge. This is clearly an unavoidable prerequisite since not only the safety and health of the patient depends on it, but also the safety of all the people concerned with the handling and administration of the radioisotope, including, of course, the physician himself.

The physician, under the terms of his allocation agreement with the AEC, must confine the use of radioisotopes to the purpose or purposes and at the dose level for which he has received Commission approval.

Watch for . . .

"Developments in Teletherapy"

in next month's NUCLEONICS. It is the subject of a companion report by Dr. Marshall Brucer which presents additional information on cancer therapy with radioisotopes.

Impact of Radioisotopes in Cancer Research

By Shields Warren
Director, Division of Biology and Medicine U. S. Atomic Energy Commission Washington, D. C.

(Dr. Warren summarized the entire Symposium and concluded with the following statements.)

Radioisotopes have proved extremely potent tools for cancer research. The Atomic Energy Commission recognizes the special value to the complex field of cancer research offered by isotopes, and has made them available at well below production costs when they are to be used in cancer research, diagnosis, and therapy.

There are still many isotopes whose possible value for the control of cancers have not yet been explored. Some of them have a very short half-life and, hence, cannot be transported far away from the reactors in which they are created. To permit this exploration, the AEC has established three cancer hospitals for research purposes, two already functioning, one at Oak Ridge, the other at Brookhaven, and a third to be opened this coming year at the Argonne National Laboratory and the University of Chicago.

* * *

The Symposium on Cancer Therapy with Radioisotopes, which was held on December 28, 1951, at Philadelphia, Pa., as part of the program of the annual meeting of the American Association for the Advancement of Science, was sponsored by the Oak Ridge Institute of Nuclear Studies and the Isotopes Division of the Atomic Energy Commission. The author wishes to acknowledge the courtesy of the symposium participants in making abstracts of their papers available for presentation here.

Radioactive-Tracer Techniques in Paper Chromatography

Associating one or more radioisotopes with one or more substances separated on a paper chromatogram offers the possibility of quantitative, as well as qualitative, component analysis. A simple automatic device is used to scan the paper radiometrically and locate the labeled substance

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Pest Infestation Laboratory, Slough, England

THE USE of paper chromatography as a micro-analytical tool is well established. In many instances, paper chromatography is capable of separating substances in amounts below the limits of chemical detection. In other cases, the resolving powers of paper chromatography may be undiscovered or unexploited because of the lack of suitable chemical methods of detection.

The application of radiotracer techniques to paper chromatography may permit the separated components not only to be located and characterized but to be estimated quantitatively. In the combined technique, the principle is to associate one or more suitable radioisotopes with one or more of the components of the mixture, either before or after chromatography. The components separated on the chromatogram are then located and estimated by their associated radioactivity. In some cases, the radioactivity may be used for characterizing or identifying a particular component when its association may be made to depend upon a specific chemical reaction.

Locating and estimating the radioactivity is done by systematically scanning the paper chromatogram with a Geiger-Müller counter, for example, or by clamping whole or part of the paper chromatogram to a photographic plate in the dark. In the photographic method, the radioactive zones, if sufficiently intense, will have autoradiographed themselves.

The scanning method is capable of great sensitivity and is quantitative, while the photographic method is sometimes more convenient in certain qualitative work.

Preparing the Chromatograms

The association of a suitable radioisotope with one or more bands of the resolved components of the paper chromatogram may be brought about in any one of three ways.

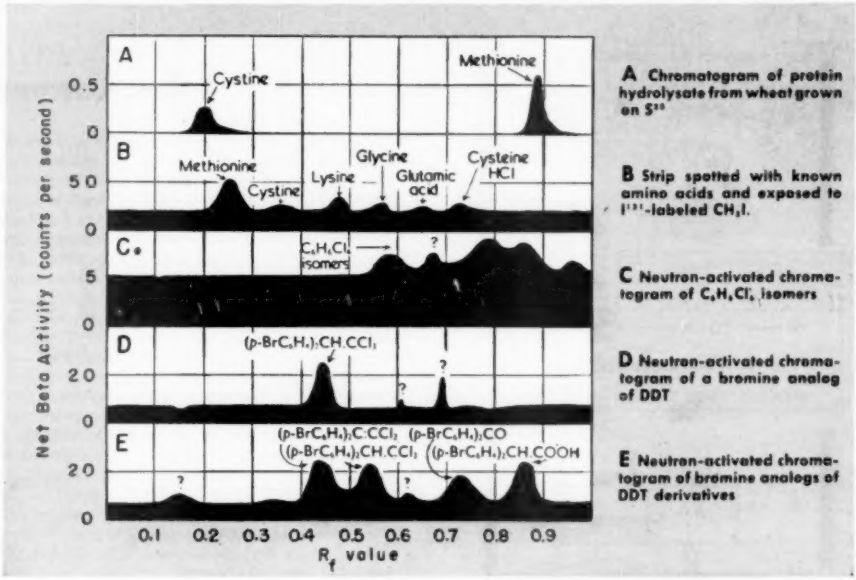
1. Labeling of mixture before paper chromatography. The mixture for chromatography may already contain one or more labeled components as in tracer experiments. For example, Benson *et al.* (*1*) studied the path of radiocarbon in the photosynthetic incorporation of this element by respiring plant cells. Labeled intermediates were located and estimated on paper chromatograms by autoradiographic and counting techniques.

The metabolism of a radioactive bromine analog of DDT absorbed by susceptible and DDT-resistant houseflies was studied (*2, 3*) by the combined techniques in which paper chromatograms were scanned by the methods to be described.

Keston, Udenfriend, and Levy (*4*) analyzed an unlabeled mixture of amino acids by treating the mixture with a labeled reagent before applying paper chromatography. The paper chromatograms were cut up into small sections which were mounted in turn below a Geiger-Müller tube and the measured rate of count plotted against distance along the strip. In this way they were able to determine quantitatively glutamic acid, serine, glycine, and alanine in a mixture of amino acids.

Another example in which the mixture already contained labeled components is illustrated by radiochromatogram *A* in the chart opposite. A paper chromatogram was run on a protein hydrolysate prepared from wheat grown on a solution containing S^{35}. It was scanned radiometrically and the radiochromatogram shown was obtained by plotting the S^{35} activity against the R_f value.† The two peaks correspond to the cystine and methionine biosynthesized in the plant.

* Fellow of the Commonwealth Fund of New York. PRESENT ADDRESS: Agricultural Experiment Station, University of California, Berkeley, Calif.



2. Treatment of the paper chromatogram with a labeled reagent. The possibilities of this method have received little attention. We have made experiments on the possible location of certain amino acid groups by methylation with I^{131}-labeled methyl iodide. No attempt has been made to apply this particular reaction as a quantitative tool, and its description here is merely included to illustrate the principles of the method which, it is believed, has considerable potentialities.

The important condition for the successful application of this method is that a labeled reagent be chosen which will selectively react with one or more of the compounds separated on the paper chromatogram but not with the paper material itself.

A strip of Whatman No. 1 paper was spotted with solutions of different amino acids, dried, and exposed to methyl iodide-I^{131} vapor at room temperature. Methylation of the amino acids resulted in the liberation of I^{131} in the amino acid zones, particularly in the methionine zone, probably as a result of the formation of the methyl methionine sulphonium iodide. After pumping off the excess methyl iodide, the paper was scanned radiometrically. The plotted radiochromatogram is shown as *B* above. The high background was apparently due to some methylation of the paper.

3. Neutron activation of the paper chromatogram. In this method, the finished chromatogram undergoes neutron irradiation in a reactor after the residual solvent is dried off. For the success of this method, the separated components must contain or be associated with an element of suitable activation cross section so that it can be readily assayed against any background radioactivity of the paper chromatogram itself.

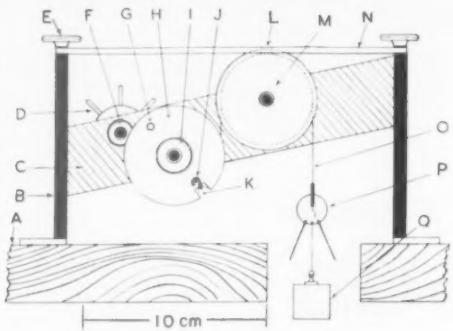
Fortunately, neither carbon, hydrogen, nor oxygen of cellulose possesses significant neutron activation cross sections in this respect, and it was found that in washed Whatman No. 1 paper the wide range of trace metals almost certainly present did not give rise to any serious effects under the moderate conditions of some experimental irradiations in the Harwell reactor.

This method has been applied successfully to the radioactivation of bromine containing organic compounds by taking advantage of the $Br^{81}(n,\gamma)Br^{82}$ reaction. For example, an inactive bromine analog of DDT and three derivatives were separated on a reversed phase paper chromatogram (*3*). The chromatogram was then irradiated for three days in the Harwell reactor at a flux of 10^{10} n/cm²/sec and was scanned a few days later. The resulting radiochromatogram obtained is shown by *E* above. Only the DDT analog was present on the chromatogram scanned in *D*. The small unidentified additional peaks may have been due to activated chromatographed impurities or to contamination.

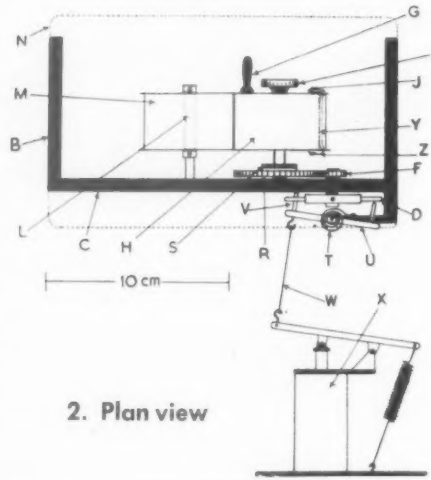
In the method of neutron activation, one important point must be borne in mind. The energy of recoil from the gamma emission in the (n,γ) reaction is usually more than sufficient to rupture any chemical bond between the target atom and the rest of the molecule. The induced radioactivity, therefore, can only be associated with the component and cannot be used as a tracer in further tests with the eluted substance.

Another complication may be due to the volatile nature of the recoil-freed isotope which can result in loss of activity and contamination of other parts of the chromatogram. For example, in the neutron activation of

† The R_f value is the distance traveled by the individual band divided by the distance traveled by the solvent front.



1. Front elevation



2. Plan view

How Automatic

Paper strip O is wound around 5.05-cm drum H and passes over 5.05-cm idler roller M under tension due to 100-gm weight Q that is fastened to the free end of strip O by means of "bull-dog" clip P. Each drum possesses a 3-mm flange on both sides. The other end is held to drum H by spring-steel wire Y passing through drum slot K. The wire is anchored to the drum H at J and screwed on the opposite side at Z. Drum H drives an eight-bladed escapement wheel D by a 4:1 gear F-R so that $\frac{1}{8}$ of 1 revolution of D allows strip O to advance, under tension, almost exactly 0.5 cm. The diameter of drum H is such that the changing thickness of paper on the unwinding drum has a negligible effect on the distance the paper moves with each escapement movement. The mean value of this distance is exactly 0.5 cm for the average chromatogram. Roller M is mounted exactly below a 1½-inch × 0.5-cm slot L cut in the platform N so that a transverse 0.5-cm section of strip O is exposed through the slot.

The over-all effect is that for every escapement movement consecutive 0.5-cm sections of the paper strip are exposed to the thin end-window WI of the Geiger-Müller tube GM which is housed inside the lead castle LC. Milled nuts E allow the platform to be removed for cleaning purposes, etc. Heavy frame B is screwed to the edge of laboratory bench A through which a suitable hole is cut for the descending strip O. Drum and roller shafts run in phosphor-bronze bearings mounted in bearing plate C.

To date, scanning has been limited to beta counting, the Geiger-Müller tube being relatively insensitive to the gamma rays from bromine-82, iodine-131, etc. Platform N must be sufficiently thick to eliminate all beta particles from neighboring but unexposed sections of the strip, an important factor in the resolving power of the scanner; ½-inch steel plate has been found to be satis-

organic bromine compounds, the recoil-freed bromine is probably present in part as hydrogen bromide. It was found, however, that if the paper strip were rolled up with a second plain strip of paper, the resulting contamination was negligible.

One possible application is to the analysis of a mixture of the isomers of hexachlorocyclohexane, the gamma isomer of which is a well-known insecticide. A mixture containing 10 μg of the α, β, γ, and δ isomers was chromatographed under the conditions used for the DDT analogs (*3*). The chromatogram was then irradiated in a flux of 10^{11} n/cm²/sec for one week and scanned a fortnight later. The radiochromatogram obtained is shown in C, the peaks of which are caused by S^{35} arising from the chlorine of the partly separated isomers by the $Cl^{35}(n,p)S^{35}$ reaction. This particular application is being investigated further.

Radiometric Scanning

Having prepared the paper chromatogram so that the resolved components are labeled or associated with a suitable radiotracer, the distribution of the tracer must be determined quantitatively.

Fink *et al.* (*5*) have located I^{131}-labeled compounds by placing the chromatogram against an X-ray plate in the dark so that the radioactive zones could be located autoradiographically after fixing and developing the exposed plate. This method does not lend itself easily to quantitative work, and it is far less sensitive than counting techniques.

It has been estimated (*6*) that, to obtain a reasonable contact autoradiograph of a Br^{82}-labeled compound, a radioactive disintegration density of the order of 10^9 disintegrations per cm² (of paper chromatogram, in this case) would be required. If this figure were obtained, say, in a 24-hour exposure, it would correspond initially to about 0.5 microcuries of Br^{82}. One hundredth of this activity, or 5×10^{-3} microcuries, could be determined to within ±5% by Geiger counting for one minute using typical apparatus.

A simple method of scanning a paper chromatogram is to cut it up into small equal sections and mount them, in

Scanner Works

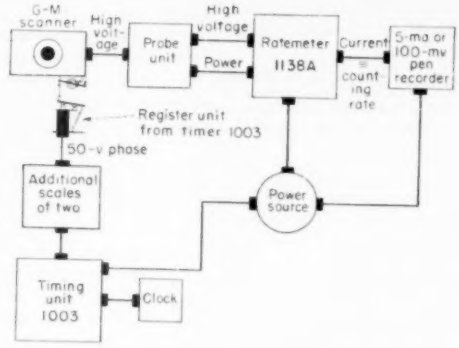
factory. Platform and frame are stainless steel, the drums aluminum.

Left prong V of escapement rocker U normally engages a blade of escapement wheel D under the tension of a small spring T attached to the rocker and frame. The armature of solenoid X momentarily pulls back rocker U via connecting rod W against the spring; when rocker U returns to normal position, D rotates $\frac{1}{8}$ of a complete revolution but no more. Friction clutch S becomes disengaged by relaxing milled nut I so that drum H is free of R and, hence, the escapement mechanism. New strips can then be wound up by means of handle G.

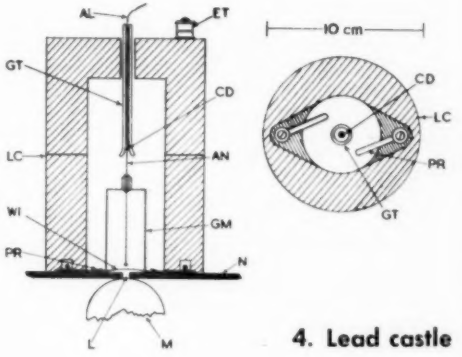
Lead castle LC is in two parts to facilitate handling. Tube GM is placed exactly over L. The lower half of LC is then lowered into position so that prongs PR engage the GM flange. The top half of LC is then placed in position so that contact disk CD engages anode AN. High-voltage and ground connections are then made at AL and ET. Insulating glass tube GL is flared at the lower end to guide AN onto CD.

Solenoid X is simply the electromechanical register unit taken from a type 1003 timing unit which is available in many laboratories equipped for beta counting. Its operation requires 50-v d-c pulses which can be drawn from the timing unit at intervals of $\frac{1}{2}$ or 1 second, or $\frac{1}{2}$ or 1 minute. By inserting additional scale-of-two units, solenoid X can be made to operate at 2-, 4-, or 8-minute intervals, etc. The probe unit amplifies pulses from tube GM and feeds them to a type 1138A ratemeter.

The 0–100 mv potential difference across the output potentiometer is proportional to the mean rate of count; alternatively the ratemeter output may be obtained as a 0–5-ma current in the same circuit. This output is fed to a pen-recording milliammeter or to a self-balancing potentiometer. The rate of count is thus automatically plotted against distance along the strip.



3. Unit-to-unit connections



4. Lead castle

turn, below an end-window Geiger tube. This method is very tedious, and unless each section is cut exactly and mounted precisely, errors will result.

Automatic scanning device. The four diagrams and text above show the components and working order of a device for automatic scanning of 1⅛-inch unidimensional paper chromatograms. Whatman No. 1 paper is conveniently available in rolls of this width. Two-dimensional chromatograms are scanned by cutting the sheet into the equivalent number of strips as described later.

The advantages of this device are: 1) The paper chromatogram is automatically scanned in a geometrically uniform manner. 2) The movement of the paper is controlled by a simple escapement mechanism that is operated by conventional timing equipment. 3) Provision is made for plotting radiochromatograms automatically. 4) All parts of the scanning unit are easily accessible for cleaning purposes, decontamination, etc.

In our experience, the milliammeter recorder was more suitable than the self-balancing potentiometer because the tendency of the latter to overbalance gave rise to fluctuations greater than the intrinsic statistical fluctuations of particle counting. The statistical fluctuations of the ratemeter output for a given mean rate of count can be modified by the variable capacitance of the integrating circuit of the ratemeter. The corresponding integrating time must be less than the time intervals of the scanner or the ratemeter will not be able to keep pace. On the other hand, the integrating time must be sufficiently large for the statistical fluctuations in the counting rate to be small compared to the radioactivity peaks of the chromatogram.

Quantitative Interpretation

A separated component will normally be distributed over several sections of the paper chromatogram. Ideally, the counting geometry will be the same for each section. The weight of the component is invariably small compared to the weight of the paper, so that self-absorption of the beta particles assayed will depend only

TABLE 1 Effect of Paper Density Variation on Self-absorption

Isotope	Proportion of beta particles unabsorbed by paper of mean density 8.785 mg./cm.²	Variation of self-absorption correction factor corresponding to ±10% variation in paper density
C^{14}	0.366	±7.4%
S^{35}	0.431	±6.5%
Br^{82}	0.787	±2.4%
I^{131}	0.828	±1.9%
Cl^{38}	0.843	±1.7%
P^{32}	0.957	±0.5%

upon the density or weight per unit area of the paper strip. For practical purposes, the density can be considered constant.

On this basis, the total weight w of the labeled component is proportional to the sum total of the net rates of count (corrected for background, radioactive decay, deadtime losses, etc.) of the relevant sections, i.e.

$$w = K\Sigma a \qquad (1)$$

where a is the corrected net rate of count of each relevant section. The constant K depends upon the specific radioactivity of the original component and upon the over-all counting efficiency.

In practice it has been found convenient to determine K by scanning a chromatogram run with a known weight of compound of known specific activity. Its position also serves to identify the peaks of the original chromatogram.

When the radiochromatogram is plotted as net rate of count against distance along the strip, it is proportional to the area enclosed by the relevant part of the curve (see below). With the counter described, it has been found convenient to measure the areas plotted on the recorder by means of a planimeter. In comparing different radiochromatograms quantitatively, it is important that they be plotted on the basis that the total radioactivity is the product of the mean rate of count over the relevant sections and the distance in an absolute sense over which the radioactivity is spread. For the purposes of identification, however, the R_f value is the important property, and the radiochromatogram should then be plotted as net rate of count against R_f value. Other factors of significance in quantitative work are discussed below.

Decay corrections. Usually the time taken to scan a unidimensional paper chromatogram is small compared to the half-life of the isotope being assayed. Thus corrections for decay may be applied to the measured areas as a whole and based on the mean time of scanning. When the time of scanning is not relatively small, the time scale corresponding to each part of the strip must be recorded and different corrections applied according to position on the strip.

Geometry effects. Ideally, the geometrical distribution of radioactivity would be the same for every exposed section of the paper chromatogram. In practice, variations occur, especially in strips cut from a two-dimensional sheet when the radioactive zone would not be expected to be in the middle region of the section, except by chance.

The beta-particle sensitivity of an end-window-type Geiger tube varies according to the position of the source below the window; the more off center the source, the less the sensitivity. For this reason, Bournsell (7) has used a large-area window tube for scanning. In unidimensional chromatograms, however, the radioactive zones appear to be sufficiently similar to permit assays based on adequate controls with known amounts of radioactive material.

For two-dimensional chromatograms, a tube of larger window area than the one illustrated on page 55 might be desirable. A simpler alternative, however, is to cut the two-dimensional sheet into the equivalent number of strips sufficiently narrow to eliminate significant geometrical effects. A width of 1 cm has been found to be effective; strips of this width are run over the middle of the drum. This can be done by simply winding the narrow strips in the middle of drum *H*.

Deadtime corrections. Corrections for counter deadtime or quench time losses for every section of a radiochromatogram would be tedious to make. For this reason, it is recommended that quench and ratemeter paralysis times be kept to a minimum. For example, if a Geiger counter is effectively quenched for 100 μsec following each pulse, then this correction for a maximum rate as high as 100 counts per second will be only 1%. Since the rate of count necessarily varies from zero to zero through the maximum for a resolved component, the deadtime error in its estimation will be less than 1%.

Self-absorption. Self-absorption of a constant source will vary according to the variations in paper density. Corrections for this factor in quantitative comparisons along a unidimensional strip are tedious, but the following calculations indicate the effect to be small in any case. For the purpose of the calculation, it was assumed that a resolved component would be spread over about 5 cm² of paper. The coefficient of variation in mean density of 5-cm² sections cut from a random sheet

TABLE 2 Radiometric Assay of Br^{82}-labeled Derivatives Separated on Paper Chromatograms

Compound or mixture	Weight applied to chromatogram (micrograms)	Recovery by scanning (%)	Remarks
p-$BrC_6H_4CH_2CH_2CO_2CH_3$	6.2	100	
"	1.6	104	
"	1.0	111	Labeled component applied singly
"	2.0	105	
"	5.0	95	
"	5.0	92	
p-$BrC_6H_4CH_2CH_2CO_2CH_3$	1.0	111	
+ *p*-$BrC_6H_4CCl_3$	0.5	97	
p-$BrC_6H_4CH_2CO_2CH_3$	50	107	Applied as a labeled mixture
+ *p*-$BrC_6H_4CCl_3$	50	118	
+ *p*-$BrC_6H_4CH_2COOH$	50	100	
p-$BrC_6H_4CCl_3$	20	126	Applied as a mixture; activated after chromatography
+ *p*-$BrC_6H_4CO_2H$	20	92	
+ *p*-$BrC_6H_4CH_2COOH$	20	96	
	Average recovery	101.2	

of Whatman No. 1 paper was ±3.9%; mean density was 8.785 mg/cm².

The effect of a ±10% variation on the self-absorption and on the corresponding corrections in the assay of some typical isotopes was calculated by means of Libby's self-absorption equation (*8*). The results are shown in Table 1. Even in the case of the soft beta emitters, it is unlikely that this variation will seriously impair quantitative work.

Resolution. When two or more labeled components are incompletely resolved, one must decide arbitrarily how to divide the area of the plotted radiochromatogram. Alternatively, an ingenious technique developed by Keston *et al.* (*4*) may be useful. In this method, one of the unresolved components is labeled by means of a second isotope of sufficiently different radiation characteristics to enable its boundary on the chromatogram to be determined by selective scanning.

Corrections for recorder drum speed, rate of scanning, and background. The radiochromatogram is plotted by the recorder as counting rate (ordinate) against distance along the strip (abscissa). In Eq. 1, the activity or rate of count a will be constant (neglecting statistical fluctuations and decay) for each exposed section; Σa is therefore proportional to the area A enclosed by each radioactivity peak of the radiochromatogram. Thus $w = K'A$, where K' depends upon the over-all counting efficiency (observed rate of count per absolute disintegration rate) and upon the units in which A is measured.

In practice, it is convenient to adjust the recorder drum speed (provision is made for this in the majority of recorders) so that radiochromatograms plotted from $R_f = 0$ to $R_f = 1$ at different scanning rates will be represented by equal or comparable distances along the recorder paper. The scanning rate will be varied (by altering the timer-controlled intervals between pulses fed to the scanner solenoid) according to the level of activity on the paper strip. For example, as discussed later, low activities require a lower scanning rate than will high activities for the same statistical accuracy.

Corrections for differing recorder drum speeds and scanning rates in quantitative work are then made in the following manner: Suppose, in the calibration of the apparatus for quantitative work, a known weight w of a labeled substance is scanned. Let s be the scanning rate, d the recorder drum speed, and r the rate of count corresponding to unit scale (ordinate) of the recorder. Let A be the area enclosed by the radioactivity peak corresponding to the labeled substance of the radiochromatogram. This area on the recorder paper may be measured in any convenient unit (to suit a particular planimeter, for example).

Area A must be corrected for decay in the usual way and for background, which is simply the observed counting rate over that part of the strip free of labeled material. Then $K' = w/A$.

A second strip containing an unknown weight w' of the same labeled substance is now scanned at a rate s' and recorder drum speed d'. Let A' be the corresponding net area on the radiochromatogram, and r' the rate of count equivalent to unit scale of the recorder. It follows that

$$w' = K'A' \frac{ds'r'}{d'sr} \qquad (2)$$

In the apparatus described above, r'/r will be $10^{\pm n}$, where n is 0, 1, 2, 3, etc., corresponding to the sensitivity ranges of the ratemeter. The fraction s'/s may be more conveniently replaced by t/t', where t is the timer interval or time of exposure of each section, and will therefore be a simple multiple of one second or of one minute.

Precision in quantitative work. In radiometric assays, one rarely tries to determine a labeled substance by calculating the absolute disintegration rate from the observed counting rate. Assays are usually based on the rate of count observed with a known weight of the substance under standardized conditions.

In the methods described here, assays are similarly based on radiochromatograms obtained with known weights of labeled material. Under these circumstances, mean recoveries are complete, and precision or reproducibility becomes the important point. The principal factors affecting precision, apart from manipulative errors such as micropipetting on to the paper strip, are self-absorption, statistical errors (*9*) inherent in all random particle counting, and geometry.

The effects of self-absorption have been discussed. The statistical coefficient of variation of a net count obtained as the difference between the total count N_T and the background count N_B over the same interval of time is

$$\pm 100\sqrt{N_T + N_B}/(N_T - N_B)$$

It can be shown that the coefficient of variation of an assay by scanning is

$$\pm 100\sqrt{d(A_T + A_B)}/(A_T - A_B)$$

where A_T and A_B are the total and background areas in cm/cps and d is the recorder drum speed in cm/sec.

The particular contribution of geometrical factors to variation, such as an asymmetrical distribution of active material over an exposed section, has not been investigated.

Data are available, however, on the over-all variation due to all errors, including those due to manipulation, incomplete chromatographic resolution, etc., as a result of some resolution experiments with Br^{82}-labeled derivatives. Single labeled substances or simple mixtures were resolved on reversed phase paper chromatograms (*3*) and scanned. In one case, the separated components were activated after chromatography. All recoveries were estimated in terms of a reference strip run with a known weight of pure substance and scanned. The results are shown in Table 2. They are not intended to demonstrate the sensitivity of the methods. In all cases, fairly active samples were used, and weights of the order of 1/100 or 1/1,000 of those given could have been assayed with comparable accuracy.

* * *

The authors are indebted to Mr. W. K. Cordaroy for constructing the escapement mechanism and scanning frame and to the E.R.D. Engineering Company for constructing the specially designed lead castle.

This paper was first presented in London to the Physical Methods Group of the Society of Public Analysts in May, 1951, and acknowledgments are due to the editors of The Analyst *for permission for its publication in* NUCLEONICS. *The contribution is made by permission of the Department of Scientific and Industrial Research.*

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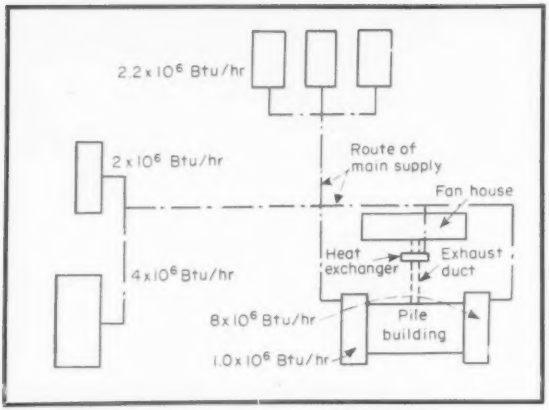

ESTIMATED COSTS AND SAVINGS

Capital cost of entire installation.....	£29,700
Interest and depreciation at 7%.....	2,079
Additional air pumping power.....	1,150
Water pumping power.....	204
Maintenance.....	297
Total running costs per annum.....	3,730
FUEL SAVING of 7.0×10^6 BTU/hr for 3,000 hours per annum, at 7 shillings per 10^6 BTU.....	7,300

FIG. 1. Water from heat exchanger is carried by pipes in underground ducts to buildings to be heated and then is returned to heat exchanger. Maximum loads are shown. Estimated savings achieved by heating buildings this way is given at right

Utilization of Waste Heat from the British Experimental Pile

Installation of a heat exchanger so designed that it does not affect the operation of BEPO adversely has made it possible to use part of the 6,000 kw removed by the pile cooling system for heating laboratory buildings

By J. WALKER and H. J. GROUT
Atomic Energy Research Establishment
Harwell, England

THE BRITISH Experimental Pile is a natural-uranium, graphite-moderated pile with a nominal heat output of 6,000 kw that normally is removed by an air cooling system that exhausts the heated air to the atmosphere. The recovery of a substantial fraction of the heat contained in the exhaust cooling air appeared to be worthwhile.

By late 1950 it became evident that recent advances in the design and construction of uranium fuel elements would enable BEPO to operate at higher temperatures. This made it both technically feasible and economically justifiable to install a heat exchanger to supply hot water for space heating and domestic supplies to neighboring buildings, shown in Fig. 1.

Design Specifications

Provision was made in the original design for a pit in the outlet underground duct through which the cooling air flows from the pile to the exhaust blowers and stack.

To choose the optimum design for the heat exchanger, a study was made of the following factors:

1. Inlet and outlet water temperatures to the exchanger and their effect.
2. Pressure drop across the heat exchanger. (Pressure drop and draft loss are synonymous.)
3. Air temperature drop in the heat exchanger and its effect on the characteristics of the exhaust blower.
4. Change in pile system resistance (pressure drop) and change in air throughput caused by addition of a heat exchanger.

To estimate the effect of these factors, an analysis of waste heat recovery and pile performance was made, with computations based on bare-tube heat exchangers with staggered tube arrangements of constant cross section but varying numbers of tube rows. Such a heat exchanger is diagrammed in Fig. 2; the staggering of the tubes is evident.

In practice an extended-surface heat exchanger is the most suitable because the added heat-transfer area makes it possible to achieve higher efficiency.

But it was felt that the results obtained with simpler calculations based on a bare-tube exchanger would be sufficiently accurate for a preliminary specification.

A number of high-speed centrifugal blowers exhausting the pile outlet duct sustain the pile cooling system. These blowers are constant-speed machines, and the installation of any heat exchanger will increase the over-all system resistance as well as alter the blower characteristics.

The pile cooling system pressure drop and the exhaust blower characteristics without any heat exchanger are shown as solid lines in Fig. 3. The resistance of the system increases as the air flow increases; at the same time, an increase in system resistance decreases the amount of air that the exhaust blowers can pump through the system. The system is operated, therefore, at the point where the capabilities of the blower match the system resistance.

Adding a heat exchanger will raise the system resistance. The characteristics of the exhaust blower are also changed since the temperature of the air is reduced as it passes through the heat exchanger. Because the colder air has a higher density, fewer cubic feet must be pumped to achieve the same air flow in lb/hr.

Operation of the system is depicted in Fig. 3 with two types of heat exchangers added to the system. Both deliver air to the exhaust blower at 160° F, giving the characteristic shown by the dashed line. Curve *A* shows the system resistance for an exchanger that gives high water outlet temperatures. In this case, the draft loss will be high because the mean temperature differences between the air and the water are small and, to obtain a given amount of heat from the air, the surface area of the heat exchanger must be large. The pile throughput will be reduced to M_2 as shown.

An exchanger with low outlet water temperatures and about the same total heat recovery duty will cause the system resistance to vary as shown by curve *B*. Here the draft loss is lower because the differences between the air and water temperatures are higher, making it possible to use a smaller surface area. The pile throughput is increased to M_1.

It should also be noted that high draft losses inevitably involve an in-

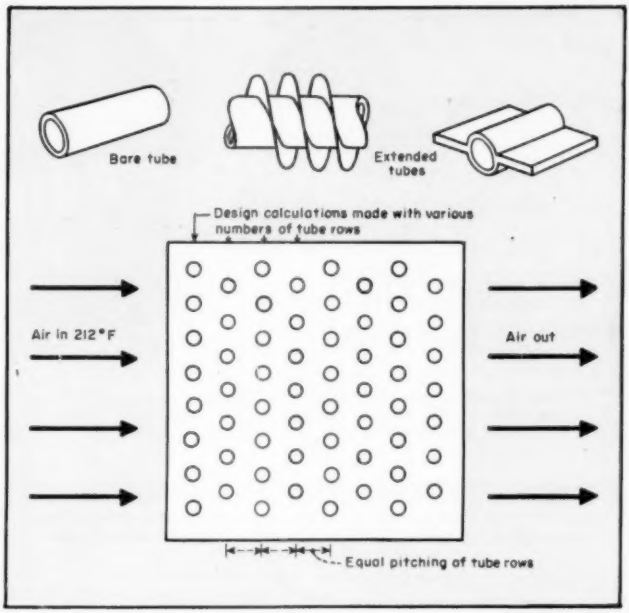

FIG. 2. Before heat exchanger was built, its effect on the cooling system and pile was calculated. Calculations were based on bare-tube exchanger with staggered tubes and constant cross section. Gilled tube in top center was used in final design

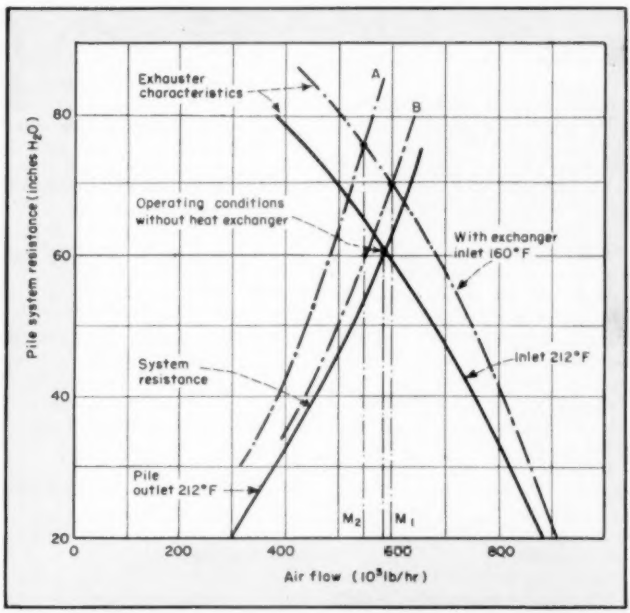

FIG. 3. Characteristics of cooling system. Adding heat exchanger raises resistance of system, as shown by curve *A* for exchanger with high pressure drop and high water temperature, and curve *B* for low drop and temperature

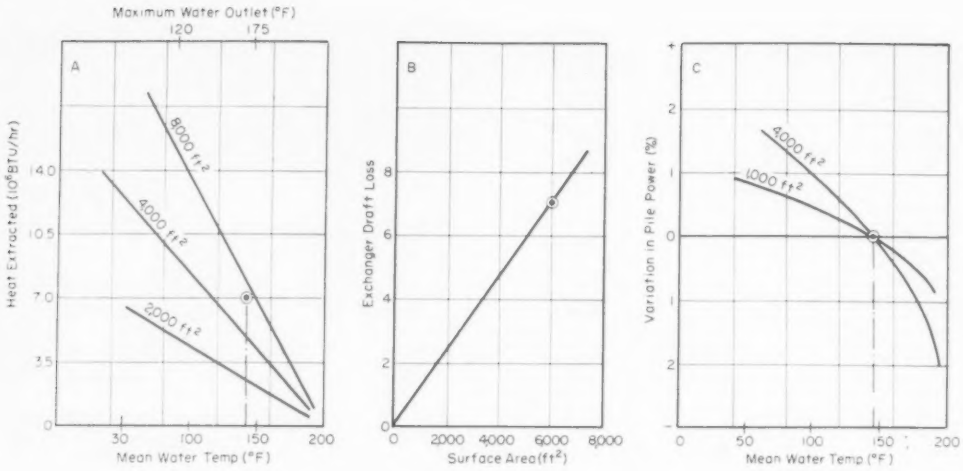

FIG. 4. Heat-exchanger design curves based on bare-tube exchanger depicted in Fig. 2. Variation in amount of heat extracted from air stream with water of different temperatures is shown in *A* for different heat-exchange-surface areas. Effect of surface area on draft loss is shown in *B*, and *C* shows how variations in heat-exchanger design can affect reactivity of pile

crease in pumping power that may negate any appreciable fuel saving.

In the discussion so far, only the effect on pile operation has been considered. However, the design of the heat exchanger had to take into consideration other limitations. The exchanger had to fit into a pit of fixed dimensions, and the outlet water from the exchanger had to be hot enough for efficient heating of buildings and for domestic supply.

Figure 4 shows the results of calculations based on the bare-tube heat exchanger. As previously discussed, a larger heat-transfer surface is required to supply the same amount of heat at a higher temperature, curve *A*. But a larger heat-transfer area causes a larger draft loss in the exchanger, curve *B*. And the reactivity of the pile is affected by the temperature of the water in the heat exchanger, curve *C*, because the reactivity and thus the power of the pile vary with the pile operating temperature. The operating temperature, in turn, is determined by the amount of heat removed by cooling system.

The circled points in Fig. 4 are the compromise chosen as a guide for drafting preliminary specifications. Taking into account the additional pumping-power costs that result from the draft loss through the heat exchanger, the specifications called for a unit that would meet the following minimum requirements:

Duty: 7.0×10^6 BTU/hr

Air flow: 600,000 lb/hr at 12 lb/in² absolute, and 212° F

Water inlet: 130° F, outlet 160° F

Air pressure drop: Not to exceed 7 in. H_2O

Space available: 9 ft high, 10 ft wide, not more than 4 ft deep.

The proposals made by Serck Radiators, Ltd., Birmingham, England, for a copper-finned-tube exchanger of conventional design with a duty of 7.5×10^6 BTU/hr at 5.6-in. H_2O draft loss, were finally accepted.

Description of Installation

The selection of buildings to be incorporated in the scheme and the layout of the supply mains was determined largely by the necessity to reduce capital costs. This entailed utilizing existing ducts for water pipes where possible, and the supplying only of buildings where the installed heating system could either accept pile heat directly or where only minor modifications were required.

The pile exhaust outlet duct is underground, and the exchanger is installed immediately after the outlet filter plant. The exchanger is provided with a by-pass damper for balancing output and demand.

The primary water-distribution circuit is 6-in. mild steel lagged pipe. It is fitted with a header tank, and isolating and by-pass valves. Circulation is provided by a 30-hp centrifugal pump with a maximum duty of 500 gal/min at a 56-ft head.

The primary circuit is laid for the most part in already existing ducts; where new ground had to be broken, the 6-in. mains are laid in earthenware pipes buried directly in the soil. This form of construction was developed by the Ministry of Works, London, who were responsible for design and installation of the supply mains and for building installations.

Each building will be supplied with the correct quantity of hot water either directly to existing hot-water radiators or through secondary water-to-water heat exchangers.

Thermostatically operated valves are installed to by-pass the primary circuit in the event of overheating, and to allow steam to be used in the system during periods when the pile is shut down. The latter provision is necessary because the operation of BEPO requires regular shut-down periods. Heat from the exchanger is expected to be available not less than 85% of the time during the winter months.

To date, one building is being supplied with heat from the exchanger. It is hoped that the others will be on load by the winter of 1953.

Berkeley INSTRUMENTS FOR SCINTILLATION COUNTING

Berkeley SCINTILLATION COUNTING HEAD Model 260

A directional gamma detector with ½" lead wall shielding and 3" lead plate with 13/16" aperture. Utilizes a thalium-activated sodium iodide crystal. Built-in cathode follower delivers output pulse to drive any scaler of .25 volt sensitivity. Plateau length is approximately 100 volts with Co^{60} gamma source; plateau slope is approximately 2% per 100 v.

Berkeley UTILITY SCALER Model 110

As a universal laboratory instrument for nuclear work, this instrument provides direct reading of results in digital form. Resolution to 5 microseconds, counting rate to 1,000 cps, and capacity to 999,999. Regulated high-voltage power supply of plug-in construction provides a continuously variable output from 0 to 2,500 volts. A simple reversal of parallel connections converts to a negative supply variable from 0 to −2,500 volts. Scaling factors of 100, 200 and 400 are provided with corresponding output signals available at standard accessory socket, to drive external register, metering circuit, computer, or other auxiliary device. Provision is also made for predetermined counts of 1,000, 2,000, 4,000, 10,000 or 20,000. Standard accessory socket permits use of predetermined timers, loudspeakers, other accessory devices.

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Radium Hazard in an Aircraft Instrument Shop

By R. K. SKOW
U. S. Naval Radiological Defense Laboratory
San Francisco, California

TABLE 1—Maximums Permissible According to NBS Handbook H-27

Hazard	*Detection*	*Maximums permissible*
Radon in shop atmosphere	Collected in evacuated flask through dust-removing filter (once every six months)	10^{-11} curie/liter (630 dpm/ft^3)
Radium dust in shop atmosphere	No method specified	None specified
Radium deposited in the body	Expired air collected in special flask, tested for radon content (once every six months)	10^{-12} curie/liter of radon in expelled air (0.1 μg radium in body)
Radium deposited on floors, benches and other surfaces	Ultraviolet light search for contamination; G-M counter	None specified
Beta-gamma radiation	G-M counter or other suitable device	100 mr/day

TABLE 2—AEC Maximums Permissible and Results of Tests

Hazard	*Detection (including test)*	*Maximums permissible*	*Contamination found in test*
Ra dust in atmosphere	Electrostatic precipitator or filter paper sampler	5×10^{-12} μc/cm^3 alpha (0.33 dpm/ft^3)	0.2–24 dpm/ft^3 alpha
Ra contamination (fixed) on working surfaces	Direct surface measurement with alpha counter	2,000 dpm alpha from area of 150 cm^2	5,000–200,00 dpm alpha
Ra contamination (removable) on working surfaces	Smear test with 2-in.^{2} filter paper wiping over 12 in.^{2} of surface	0 dpm alpha	50–10,000 dpm alpha on wipes
Ra on hands	Portable alpha counter or other suitable device	0 dpm alpha	20–5,000 dpm alpha
Ra on clothing	Direct surface measurement with alpha counter	1,500 dpm alpha from area of 150 cm^2	1,000–7,000 dpm alpha
Body exposure to external radiation	Film badges, pocket dosimeters, G-M counters	60 mr/day gamma	2–4 mr/hr gamma

Like most industrial and military aircraft-instrument repair shops, the one at the U. S. Naval Air Station, Alameda, California, followed the control measures set forth in Handbook H-27 of the National Bureau of Standards to protect workers against health hazards caused by the radioactive luminous paints used on the instrument dials. A survey of the shop showed that the required tolerances shown in Table 1 were being met. But the tolerances prescribed by the AEC for work with alpha emitters were being exceeded, as is shown in Table 2. A complete decontamination of the shop, coupled with new operating procedures and precautions, has made it possible to meet most of the AEC requirements, thus giving the workers added protection.

Old System

The shop was divided into a dial painting room where the dials of all instruments to be repaired were stripped of paint and where radium dials were painted, and the instrument repair shop where, besides repair work, nonradioactive fluorescent dials were painted. Under old procedures, only the dial painting room was monitored for radioactivity, but the survey that is summarized in Table 2 showed that alpha contamination of the hands was greatest among the instrument mechanics and least among the dial painters, who wore rubber gloves.

The greatest airborne contamination was found in the vicinity of the paint stripping operation, a wet process carried out under a standard ventilated hood. Airborne alpha contamination in the dial painting room was as high as 2,240% of the AEC maximum, even though the radon concentration in the atmosphere was 20–160 dpm/ft^3, well within the limit set by Handbook H-27. Alpha contamination of clothing was highest among the paint-stripping operators.

Nonradioactive dials contaminated. Contamination of workers' hands and of benches in excess of the maximum permissible was found in sections where

only fluorescent paint is applied. This contamination was attributed to the dial stripping procedure. Both radioactive and nonradioactive dials were stripped of paint in the same bath. After stripping, alpha activities of 28,000 and 12,600 dpm on the dials and 720 and 668 dpm on wipes were obtained for radium-painted and fluorescent-painted dials, respectively.

New Control Measures

To eliminate the above-maximum activities in the shop, a thorough decontamination was undertaken. Decontamination was continued until alpha contamination values were below the maximum and wipe tests were essentially negative.

After decontamination was completed, new control measures were instituted. The instrument mechanics are included under this system, and the repair section is now regularly monitored.

Paint stripping. Radium and fluorescent dials are now stripped separately. A new stripping bath removes residual dial contamination more effectively. In addition, the rinsing technique was modified.

Dust control. A special paper with a moderately adhesive wax surface is used to cover the floor, the inside of dial painting hoods, and all other surfaces in the dial painting room. Because of the wax surface, much of the radium dust is trapped and is not re-released to the atmosphere. This paper is renewed daily. Outside the dial painting room, the paper is used to cover work benches only.

Contaminated tissues and wipes are deposited in a paper bag kept inside of each hood. These bags are sealed under the hood, placed in a waste container, and removed from the shop daily.

Each operator is responsible for cleaning up his bench and the area around it. Ultraviolet sources are used to facilitate cleanup. Any luminous material left after the waxed paper is removed is picked up with a piece of masking tape. Before the protective paper layer is applied again, all the surfaces are vacuumed with a commercial cleaner equipped with a water trap and paper filter that prevent dispersal of collected dust.

Other precautions. An hour a day is provided for area and personnel cleanup. Each weekend, trained decontamination crews clean the dial painting room thoroughly.

Paint mixing is done under an efficient hood. The thinner is added directly to the vial of dry paint. Paint mixing is kept to a minimum

The ventilation system has been modified to eliminate stray air currents. Spreading of contamination has also been reduced by providing cloth bootees that are worn over shoes only in the dial painting room. Atmospheric samples for determining long-lived alpha activity are collected frequently, and the shop is monitored weekly.

Results. Shortly after the new procedures and controls were inaugurated, it was found that contamination of fluorescent dials had been reduced to the point where no discernable activity was found in wipe tests. Contamination of cleaned radium dials was also markedly reduced.

Airborne alpha contamination was reduced to below the AEC maximum in most areas in the dial painting room, with a high of 1.24 dpm/ft^2 near the stripping booth. This is 375% of the AEC maximum, as compared to the previous 2,240%.

Since this investigation, the use of radium paint on military aircraft instruments has been sharply reduced.

* * *

A complete report of this work is given in AD-238(H), by R. K. Skow, O. J. Sobol, and Willa Wadleigh.

Capsules for Oral Administration of Radioisotopes

By RAYMOND L. LIBBY* and MANUEL TUBIS*

It has been the general practice to administer both tracer and therapeutic doses of radioiodine and radiophosphorus orally as aqueous solutions. This dosage form presents a potential hazard from a radiological safety viewpoint in that spillage and contamination may occur either during the handling or the administration of the aqueous dose. To obviate this hazard, a carefully standardized solid dosage form is desirable.

This report describes the preparation of doses of radioiodine dispensed in hard gelatin capsules.

The dosage form chosen was the hard gelatin capsule since it is readily available, easily filled and well tolerated. The choice of filler for the capsule presented a number of problems. For example, it must not cause any gastric disturbance or have any significant pharmacological action; it must be soluble in gastric juice, and it should permit the rapid release of the isotope. In addition, it should absorb the aqueous isotope solution without softening or deforming the gelatin capsule.

A number of different filler materials such as various sugars, starches, gums, and salts were tried. However, anhydrous disodium phosphate was found to conform more nearly to all of the above criteria, particularly since it combines with as many as twelve molecules of water of crystallization while still retaining a "dry" crystalline form.

The capsules are prepared and standardized as to dosage as follows: The larger half of a number 0 hard gelatin capsule is packed with 0.6 gram of anhydrous disodium phosphate. A prestandardized dose of radioiodine contained in 0.2 ml of solution is added dropwise, from a calibrated pipette, to the surface of the disodium phosphate. The open capsule is then allowed to air-dry and is finally capped. A final check on the dose of radioiodine contained in each capsule is made by determining, under standardized geo-

* Radioisotope Laboratory, Wadsworth General Hospital Veterans Administration Center, and the Department of Radiology, School of Medicine, University of California, Los Angeles, California

metrical conditions, the number of counts per capsule using a sodium-iodide scintillation counter.* The observed net count per capsule divided by a predetermined net count per microcurie, made under the same standard conditions, equals the number of microcuries of radioiodine in the capsule. The capsules are then dispensed in labeled vials which show the date and dosage.

The "disintegration time" of the capsules was determined by placing them in 25 ml of artificial gastric juice containing 0.36% hydrochloric acid and 0.1% pepsin at 37° C. With an occasional inversion, the time for disintegration varied between 10 and 15 minutes. This was sufficiently rapid for quick absorption. The *p*H of the resulting mixture was about 5, which would indicate that there should be no excessive alkalinization of the stomach contents.

To determine whether or not the administration of radioiodine absorbed on anhydrous disodium phosphate in hard gelatin capsules would have any effect on the amount of iodine taken up by the thyroid gland, doses of 2 μc were given to individuals who had previously been administered oral aqueous solutions of radioiodine. The table shows the 6- and 24-hour uptakes for a typical series of subjects who received both capsule and aqueous dosage forms of radioiodine. As shown in the table, there is relatively little difference in uptake between the aqueous or capsule dosage form at these time intervals. The differences observed are no greater than usually found in repeated uptakes.

Comparative Thyroid Uptakes of I^{131} for Capsule and Aqueous Oral Doses

	% Uptake			
	6 hr		24 hr	
Subject	Capsule	Aqueous	Capsule	Aqueous
LD	14	13	25	18.8
RN	11	11.5	15.5	19
FB	16.5	25	26	32
RLL	13	14	19.5	17.5
SJ	21	19	27	29

* Details to be published.

* * *

This article was reviewed in the Veterans Administration and published with the approval of the Chief Medical Director. The statements and conclusions of the authors are the result of their own study and do not necessarily reflect the opinion or policy of the Veterans Administration.

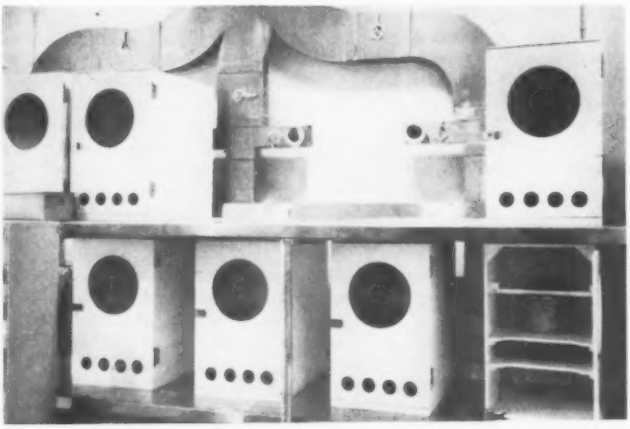
Cage-Hood Assembly for Small Animals

By JOHN T. VAN BRUGGEN
Department of Biochemistry
University of Oregon Medical School
Portland, Oregon

The care and handling of small animals metabolizing C^{14} compounds presents a special problem of $C^{14}O_2$ disposal. If CO_2 is not being collected as a part of the experimental conditions, and particularly if the experiment requires a number of animals over a prolonged period, the potential contamination of the laboratory and its personnel may be serious. In addition, close observation and frequent handling of the animals often makes it desirable to keep the animals close to, or in, the laboratory.

To minimize $C^{14}O_2$ hazards and to eliminate much of the odor and unsightliness associated with a group of mice or rats, a cage-hood assembly was designed. The assembly has been in operation for several years and appears to solve the problems recounted in the preceding paragraph.

The illustration shows a portion of the double-tier assembly that accommodates 12 hood-type containers, each of which is vented by a duct system through a blower assembly and exhaust stack above the room. The hoods are 16 × 20 and 24 in. high and are made of ¾-in. plywood finished in a glossy enamel. Each door has four 2-in. openings near the bottom which serve as air inlets. A 10-in. observation window in the door is covered with cleared X-ray film.



Cage-hood assembly for small animals. Metabolism cage in hood at lower right is held upright by sliding shelves

The back side of the box has a 6-in. vent opening in line with the center of the window. Attached to the rear of the box, around the vent hole, is a flanged cone-shaped sheet-metal

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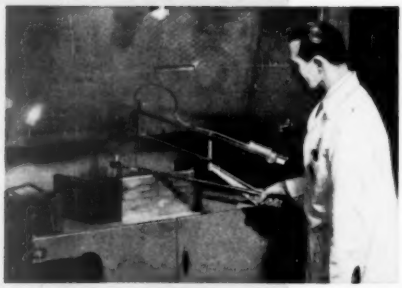

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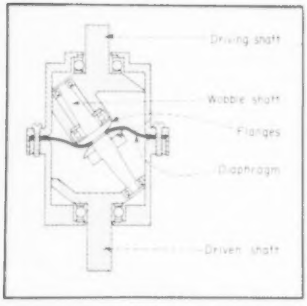
adapter that tapers in its 3-in. length to a 3-in. opening. The adapter is attached to the box with four screws through the flange on the wide base of the cone.

The duct system branches to provide twelve points of attachment of the boxes. Convenient connection between the boxes and the duct system is made without the aid of clamps. The 3-in. openings of the duct system shown in the exposed portion of the second tier have a funnel-like collar or adapter directed toward the boxes. The rim of this sheet-metal adapter is fitted with a soft, hollow rubber gasket, a material common to most refrigerator door closures. The flat flange of the gasket is held in place on the outside of the metal adapter, and the rounded hollow portion thus extends into the inner part of the funnel and serves as a gasket between the metal of the duct and the metal adapter on the back of the box. Connection of box to duct is made by sliding the box against the duct, alignment being assured by observation through the front window. The round funnel-bottom metabolism cage, shown inside one of the boxes, is supported and held upright by the sliding shelves. A tension bar serves to steady the cage and also holds in place the screen top of the cage. When urine and feces are not being collected, the shelves may be removed and animals kept in conventional wire cages in the box.

A High-Vacuum Rotary Seal

By EDWARD P. FRENCH and ACIE NEWTON
School of Mineral Sciences, Stanford University
Stanford, California

In the course of studies of liquid-metal wetting phenomena carried out as part of the work done at the Stanford metallurgy department under an Atomic Energy Commission contract, it became desirable to perform certain machining operations, such as drilling and grinding, under a molten-metal bath. To prevent oxidation of the metal bath, it was also desirable to work under vacuum. To accomplish this, it was necessary to devise a rotary seal capable of maintaining a moderately high vacuum and able, at the same time, to transmit considerable power. Mr. Newton undertook the design and construction of such a device, a diagram of which appears in the accompanying illustration.



Sectional view of high-vacuum rotary seal

The essential features of this device are a rubber diaphragm, an upper (driving) and a lower (driven) shaft in vertical alignment and a wobble shaft connecting these two and inclined at an angle from the vertical. The edge of the diaphragm is clamped between the upper and lower halves of the housing; the center of the diaphragm, through which the wobble shaft passes, is clamped between flanges, thus sealing the top half (which is open to the atmosphere) from the bottom (which is in contact with the vacuum chamber).

The wobble shaft is seated in holes bored into extensions of the driving and driven shafts, effecting a mechanical coupling of these members. When a rotary motion is imparted to the driving shaft, the axis of the wobble shaft describes two conical surfaces, each with its apex at the mid-point of the shaft and at the level of the diaphragm. This constrains the driven shaft to describe a rotary motion similar to that of the driving shaft.

The wobble shaft is set in ball-bearing mounts so that it need not rotate with respect to its own axis, and therefore the flanges bearing on the diaphragm do not slide over the rubber surface. The only motion the diaphragm undergoes is a moderate flexing to which the rubber can readily yield without disturbing the seal.

The model constructed at Stanford was tested and found to maintain a vacuum of 3×10^{-5} mm of mercury while in rotation. This performance compares favorably with static seals made with rubber gasket material.

TECHNICAL BRIEFS

• **Solidification** of molten metals occurs when metal crystals form on foreign nuclei in the melt, according to Drs. David Turnbull and Bernard Vonnegut of the General Electric Research Laboratory at Schenectady, N. Y. Without the impurities, solidification would not start unless the material was cooled far below the melting point.

• **Mutations** in corn kernels exposed to radiation increase in direct proportion to the amount of radiation to which the corn plants have been exposed during growth. Studies at Brookhaven National Laboratory, Upton, N. Y., indicated that the normal mutation rate was increased 17,000-fold in one case.

• **Two new** radioisotopes have been produced in the Canadian National Research Council's NRX reactor at Chalk River, Ontario. Calcium-41 has a half-life of 120,000 years, and actinium-229 has a half-life of 66 minutes.

• **Scaling circuit** using a ferromagnetic skin effect for pulse memory has been constructed by C. Hertz, Physics Department, University of Lund, Sweden. Typical stage of the scaler consists of two small thyratrons and a small iron-core transformer having three windings. Pulses arriving at first tube cause a small capacitor to discharge into one transformer coil, magnetizing only a thin surface layer of the core to saturation. Grid bias of the second tube is selected so that after a desired number of pulses, it discharges a large capacitor through a demagnetizing winding, thus wiping out the memory of the core for the preceding pulses.

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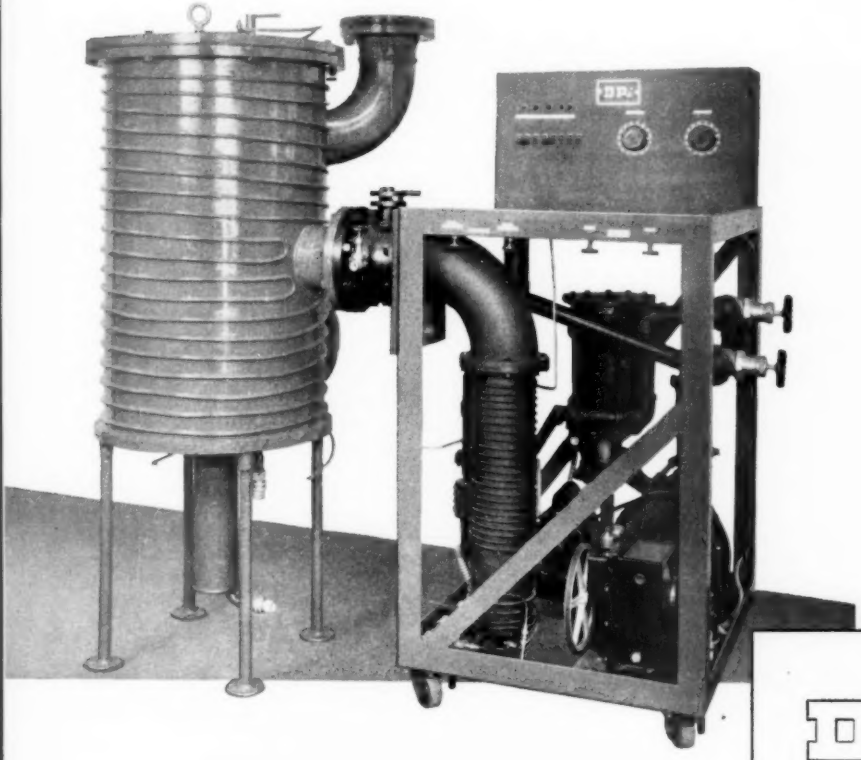

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BOOKS

The Theory of Isotope Separation as Applied to the Large-Scale Production of U^{235} (Div. III, Vol. 1B, of National Nuclear Energy Series), by Karl Cohen, edited by George M. Murphy, McGraw-Hill Book Co., Inc., New York, 1951, xviii + 165 pages, $2.

The author of this volume was the director of the theoretical division of the SAM Laboratories at Columbia University during World War II. In these laboratories, the research basic to the successful diffusion method of concentrating the U^{235} isotope was accomplished. The material for this book is taken largely from the reports of Dr. Cohen's division and its antecedents. However, a considerable number of references to British reports in the period 1940-44, and some special topics from other sources, are included.

Detailed consideration is given to centrifuges, electromagnetic methods, electrolysis, chemical exchange, thermal diffusion, and distillation. Of all available methods of isotope separation, only the mass spectrograph under ideal conditions can produce a large change in the abundance ratio of the isotopes in a single elementary process. Since for practical applications, a large enrichment of one of the isotopes is always needed, the problem of the efficient multiplication of elementary processes to produce well-separated isotopes in quantity is of great importance. Fortunately, all the methods are sufficiently alike so that their multiplication problems are very closely related. The author, therefore, devotes the first five of the total of seven chapters to a thorough examination of this common multiplication problem.

The general theory of cascades is found in these five chapters, with but little reference to applications. Yet the point of view is that of the development engineer. With losses in mind, the design and assembly of the various stages in order to yield the needed quantity and quality of product are considered in detail. "Cascade" refers to any connected arrangement of separative units such as individual centrifuges or fractionating columns. A "stage" of a cascade consists of all units operating in parallel on material of the same isotopic mole fraction.

Chapter 1 treats ideal cascades which would have a smoothly varying flow function. Chapter 2 treats the steady-state behavior of single countercurrent columns, *or* square cascades, of cascades of countercurrent columns, and of the squaring off of the top of a cascade. Chapter 3 deals with the equilibrium time of a square cascade, while Chapter 4 considers the increase in size of a cascade with losses and the determination of cascade constants. In this chapter we read that "in all cases it is useful to have experimental confirmation that cascade operation follows calculation!" Chapter 5, entitled *The Control Problem*, gives the mathematical theory of the effect of disturbances in operation on the production of the cascade. In Chapter 6 the centrifuge method is considered in some detail. The other isotope-separation methods mentioned are each presented briefly in Chapter 7, where their equations are related to the general theory.

The many graphs and tables in this volume have been designed to give quantitative aid to those applying the theory to a particular case. Although the treatment is quite general, only binary isotope mixtures are considered. Most practical separation problems—hydrogen, helium, lithium, and uranium, for example—are thereby covered. However, some of us working in this field could make use of theoretical considerations applicable to ternary and multi-component mixtures.

One misses discussions of motivations for some of the theoretical developments as well as descriptions of the most important applications. Obviously, these have been deleted for security reasons. The author maintains that to a certain extent direct experimental proofs of the theory need not be included, for "in a large measure the theory is self-evident, in the fashion of demonstrations in thermodynamics." Maybe so, but this reviewer suspects that most experimentalists always find of the greatest value those sections of theoretical monographs which are devoted to quantitative applications of the theory. Also, of course, the story of the applications of the theoretical work in this volume would make thrilling reading.

Despite this necessary omission of desirable material, the book is an extremely valuable one for all workers in the field of isotope separation. The generality of the theory and the common knowledge that very successful applications have resulted, lead to the conclusion that, in the future, the separation of binary isotope mixtures is entirely a matter of overcoming experimental engineering difficulties.

—W. W. Watson
Chairman, Physics Department
Yale University

Toxicology of Uranium, Survey and Collected Papers (Div. IV-23 of the National Nuclear Energy Series), edited by Albert Tannenbaum, McGraw-Hill Book Co., New York, 1951, xxvi + 333 pages, $3.

In reading this book, the reviewer read the title, then turned to the first chapter and read through to the end. This reading resulted in a list of critical notes and a determination to write a review that would properly set forth the weaknesses as well as the strong points of the book.

Fortunately, before submitting the review, he turned back to the title page and read all he had previously omitted. He found that all the important weaknesses he had noted were known to those responsible for the book and frankly stated. For instance, the title of the book seemed to be inadequate and possibly misleading, but this point was, to a large extent, answered on the title page by that part of the title in small print, "Survey and Collected Papers." The editor effectively covers most of the reviewer's other criticisms in the preface where he says, "It must be emphasized that the reports represent investigations directed toward rapid accumulation of knowledge for immediate use in an important war project, and they therefore may lack the completeness expected of academic research."

The reviewer feels that Paper 16 on *Studies of Porphyrin Metabolism—The Effect of Metals on Coproporphyrin Excretion* should have contained the data on the 52 rabbits that were injected with uranium. Data on only five of these rabbits and one other that had previously been injected with lead are all that are presented. If lack of space prevented inclusion of the data, some portions of the paper not related to uranium might well have been

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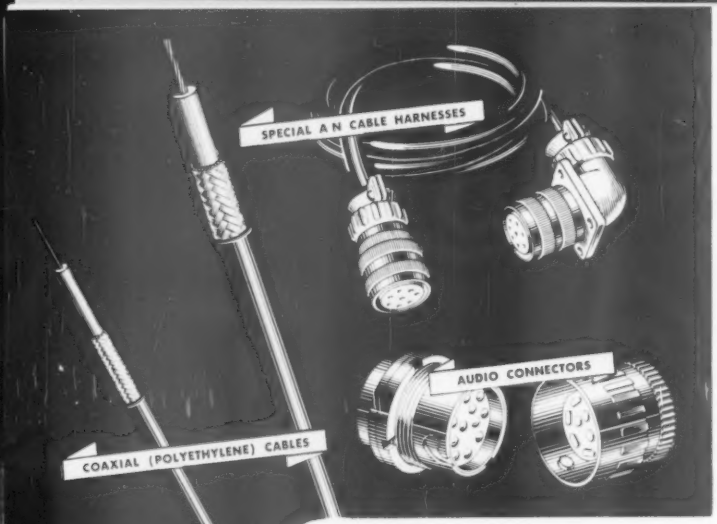

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omitted rather than the data on these 52 rabbits. Other readers may find the data on one rabbit an unsatisfactory summary of data on a number of animals.

Though this book, as the preface states, "is not intended as a complete textbook of uranium pharmacology and toxicology," it does contain information that should insure it an important place among reference books on the toxicology of and especially on the industrial hazards of uranium as one of the heavy metals.

Industrial hygienists, health physicists, and industrial physicians will find information in Part A (*Introduction to the Toxicology of Uranium*) of the book on which to base practical schemes of industrial hygiene that will provide adequate safeguards for the health of persons exposed.

Research workers interested in further investigation of the toxicity of uranium should search the *Collected Papers* (Part B of the book) for leads on problems that need further investigation and for information that will enable them to design critical experiments.

—A. E. Brandt
Health and Safety Division
U. S. Atomic Energy Commission
New York Operations Office

Applied Atomic Energy by K. Fearnside, E. W. Jones, and E. N. Shaw, Temple Press, Ltd., London, 1951, vii + 156 pages, 8/6d.

Brief chapters on modern nuclear physics and on nuclear reactors provide a clearly written introduction to this pocket-size (13 × 18 cm) book. American readers concerned with the production of radioactive materials will be pleased to see photographs of the experimental face of the BEPO reactor at Harwell and the techniques of unloading isotopes from it. Techniques of measurements, including coincidence counting, are treated briefly but adequately.

The preparation and distribution of radioisotopes is dealt with in a short chapter of 10 pages, and a list of the isotopes available at the time of publication of the book from Harwell is appended. Reference is also made to the method for obtaining radioactive materials in foreign countries.

The legal aspects of atomic energy and an abstract of the British "Radioactive Substances Act of 1948" are presented, together with a philosophical

discussion on the difficulties of international control of atomic energy.

Fifty per cent of the book is devoted to descriptions and illustrations of how radioisotopes are used in the field of research, biology, medicine, agriculture and industry. Details of the experimental work performed in the United States of America are given. Perhaps it would have been helpful to the reader if a greater proportion of specific references to the literature had been given rather than simply the name of the investigator.

A few minor inaccuracies have been detected. On page 131, for example, it is stated that barium carbonate is used to identify the interface between various kinds of oils in a pipe line.

A short bibliography and an adequate index complete the book. The authors have striven for and achieved excellent clarity of presentation.

—George G. Manov
Chief, Advisory Field Service Branch
Isotopes Division
U. S. Atomic Energy Commission

BOOKS RECEIVED

Quantum Theory of Matter, by John C. Slater, McGraw-Hill Book Co., Inc., New York, 1951. xiv + 527 pages, $7.50. (*To be reviewed.*)

Progress in Cosmic Ray Physics, edited by J. G. Wilson, Interscience Publishers, Inc., New York (or North-Holland Publishing Company, Amsterdam), 1952. xvi + 557 pages, $12. (*To be reviewed.*)

Physical Properties and Analysis of Heavy Water (Div. III, Vol. 4A, of National Nuclear Energy Series), by Isidor Kirshenbaum, edited by Harold C. Urey and George M. Murphy, McGraw-Hill Book Co., Inc., New York, 1951. xv + 438 pages, $5.25. (*To be reviewed.*)

Principles of Radio (6th edition), by Keith Henney and Glen A. Richardson, John Wiley & Sons, Inc., New York (or Chapman & Hall, Ltd., London), 1952. vii + 655 pages, $5.50. A completely revised and rewritten edition, this text emphasizes basic radio circuits, shows operating ranges of typical equipment, and gives step-by-step examples to illustrate necessary computations. Chapters on electronic test

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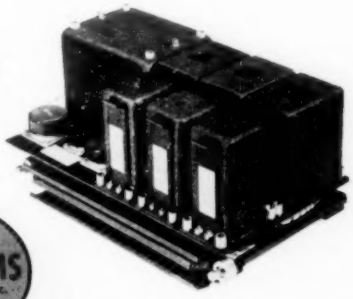

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equipment, frequency modulation, television, radar, and wave shaping circuits are also included.

Electromagnetics, by Robert M. Whitmer, Prentice-Hall, Inc., New York, 1952, ix + 270 pages, $6.65. (*To be reviewed.*)

The Design and Analysis of Experiments, by Oscar Kempthorne, John Wiley & Sons, Inc., New York, 1952, xix + 631 pages, $8.50. (*To be reviewed.*)

The Thermodynamics of the Steady State, by K. G. Denbigh, John Wiley & Sons, Inc., New York (or Methuen & Co., Ltd., London), 1951, vii + 103 pages, $1.75. This is a pocket-size monograph written as a result of studies on the theory of open reaction systems carried out at the Butterwick Laboratory of Imperial Chemical Industries, Ltd., and Cambridge University.

OTHER LITERATURE

Determination of Hemoglobin Content of Blood by X-ray Fluorescence (PB 105 300). A 7-page Naval Research Laboratory report on a new technique of measuring the X-ray fluorescence of the iron in blood to get a rapid indication of hemoglobin content. The report also suggests application of the method to urinalysis and other fields of biological testing. *Office of Technical Services, Dept. of Commerce, Washington 25, D. C., $0.25.*

Some Applications of Atomic Energy in Plant Science. This is the Government Printing Office reprint of the 211-page *Eleventh Semiannual Report of the Atomic Energy Commission to Congress,* covering the period June–December, 1951. Part 3 of the report covers the subject of plant science. Part 1 describes major activities in the atomic-energy programs during the report period, and Part 2 contains a condensed AEC annual financial report for the fiscal year 1951. *GPO, Washington, 25, D. C., $0.50.*

Price List No. 8 of Atomic Energy Project Reports of the National Research Council of Canada (Jan. 15, 1952). Titles and prices of 27 reports issued since July 31, 1951. *List available without cost from National Research Council, Ottawa, Canada.*

First Annual Report of the National Science Foundation (1950–51); 31 pages. *GPO, Washington 25, D. C., $0.20.*

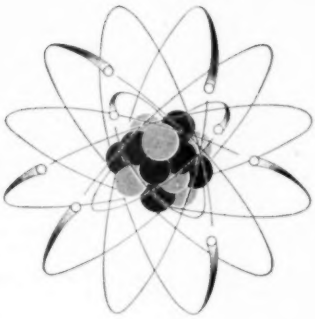
Nuclear Science in Engineering Education (TID-3011). A 17-page pamphlet containing selected references for engineering faculties. *Office of Technical Services, Dept. of Commerce, Washington 25, D. C., $0.10.*

The Merck Index of Chemicals and Drugs (6th edition). The previous edition of this encyclopedic text was published in 1940. The new edition, with 1,167 pages, contains over 8,000 descriptions of individual substances, 2,000 structural formulas, and 20,000 names of chemicals and drugs alphabetically arranged and cross-indexed. A new feature is a handy table of radioisotopes with their half-lives and type of radiation, together with a list of current medical uses of these isotopes and their compounds. *Publications Department, Merck & Co., Inc., Rahway, N. J.; regular edition, $7.50; with thumb index, $8.*

Radiation and Monitoring Fundamentals for the Fire Service. An illustrated pamphlet of 42 pages written to familiarize the professional fire fighter with radiological hazards, radiation-detection problems, and protective and decontamination measures to be taken after an atomic-bomb explosion. Elementary atomic physics and explosion effects are also covered. It is a sequel to an earlier publication, "Radiation Hazards of Radioactive Isotopes in Fire Emergencies," issued in June, 1950. *International Association of Fire Chiefs, 22 East 38th St., New York, N. Y., $0.75.*

Atomic Energy—Handbook for Speculators, Investors, by Everett C. Swanson, Sr. This booklet is published by a member of the Detroit Stock Exchange that claims to be the first investment banker in the United States to underwrite an issue of common stock for a company in the atomic field. It contains many interesting facts on the size of the nucleonics industry, the companies in it, work accomplished, and benefits contemplated. *A. H. Vogel & Co., 1646 Penobscot Bldg., Detroit 26, Mich., $1.*

ISOTOPES



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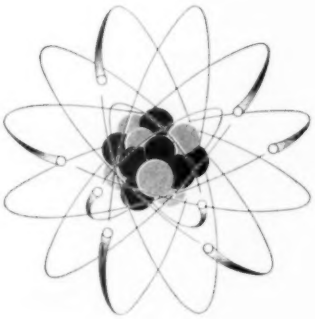

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Two Reports on Reactor Studies in, Others Due Shortly; Dean Cites Need for 7,000 More Scientists in Program

The Atomic Energy Commission let it be known last month that it will have available shortly for analysis two final and two preliminary reports on the studies four industrial groups are making on the feasibility of building and operating materials-and-power-producing reactors with private funds (NU, June '51, p. 42; July '51, p. 2).

Reports have already been received by AEC from the Detroit Edison-Dow Chemical group and the Pacific Gas & Electric-Bechtel group. No indication was given of the conclusions reached by these companies, but it was learned that AEC has asked the remaining two groups, Monsanto Chemical-Union Electric and Commonwealth Edison-Public Service of Northern, Ill., to submit preliminary reports of their findings so that all four studies can be reviewed in a more-or-less preliminary way at the same time. The latter are expected shortly, but it will be several months before it is known whether or not the prospects of privately-owned nuclear reactors are promising. Under the contracts with the companies involved, the groups working on the problem have until the middle of 1952 to complete their studies.

An objective of these privately financed studies by the groups is to give them, and industry in general, an opportunity to invest private funds in building and operating reactors "with profit in proportion to efficiency and improvements rather than on a cost-plus-fixed-fee basis." If the feasibility studies produce favorable results, step two in the program is for the companies to proceed with designing the reactor. Asked recently if any legal obstacles prevented the companies with continuing to step two, AEC Chairman Gordon Dean indicated that the Commission anticipated none, but that some could be expected should the program proceed to step three, which is construction and operation.

The Commission, through contractors, is carrying out its own studies on reactors that might eventually be used for power. These and other facts were revealed recently in connection with the release of the AEC's Eleventh Semiannual Report to Congress covering the period of July–December, 1951.

Expansion and Shortages

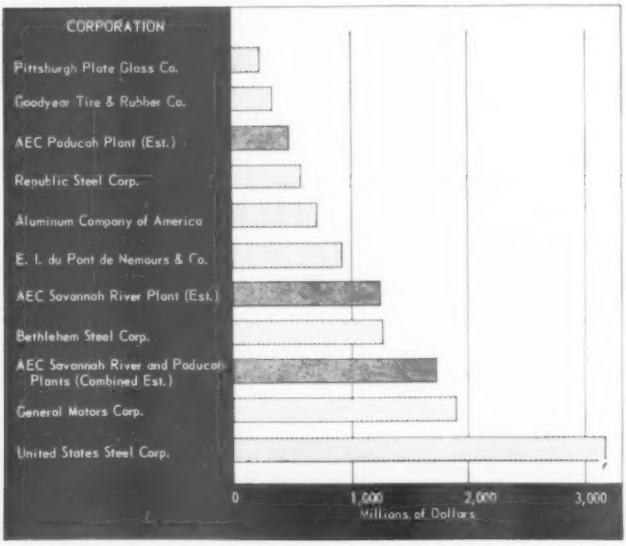
The huge expenditures for expansion of present AEC facilities and the construction of new ones were revealed in many aspects of the report. It is now estimated that the combined cost of the Savannah River plant and the Paducah, Ky., plant will come to $1,723,000,000. How this amount compares with the investments in real estate, plant, etc., of some of the major industrial corporations in the United States is seen in the accompanying graph.

Asked to comment on the additional capital expenditure of $5 to $6-billion for expansion of atomic-energy work and plants recently proposed by President Truman, Chairman Dean said that this amount would be exclusive of operating costs during the period of the late phases of construction and that it would be over and above the present program. He added that it has not been determined whether there are going to be new sites or expansions at existing facilities. One of the problems in any further expansion, he pointed out, is that of recruiting more scientists and technicians. There are some 12,000 scientists currently engaged in work for the AEC, and 7,000 additional scientists and engineers are needed. Commenting of the shortage of both, "Somebody is going to have to be robbed," he said.

Although construction proceeded on or nearly on schedule at most of the AEC's major new production facilities, material shortages created delays at the Savannah River, S. C., Paducah, Ky., and Dana, Ind., plants.

Heavy Water for Savannah Plant

In connection with the Dana, Ind., project, E. W. Reilly, manager of the plant, and Curtis A. Nelson, manager of the Savannah River project, re-



Cost of AEC's Savannah River and Paducah plants compared with investment in real estate, plant, and equipment of eight major industrial corporations

cently announced that heavy water for the Savannah River plant will be produced at Dana. Construction of the Dana plant, their announcement continued, "is of critical importance and urgency. . . . Work at Dana vitally affects production schedules which have been established by the President."

The major emphasis in AEC's latest report to Congress is on atomic energy and its applications in plant science. The scope of the research involved is discussed, together with the results of many of the experiments performed in universities and AEC laboratories.

Another section of the report is devoted to various financial statements on the Commission's operations. The United States' investment in the atomic energy program and the cumulative costs of operations from June, 1940, through June, 1951, are shown to be $2,805,411,139. The figure given for the sale of isotopes for the year ending June 30, 1951, is $453,352.

Expansion is noted in both the foreign and domestic production of raw materials, with deliveries of uranium concentrates proceeding according to schedule. The Commission reports that more phosphate fertilizer and chemical companies have been engaged to investigate the possibilities of recovering uranium from phosphoric acid produced in the manufacture of triple-superphosphate fertilizers and certain phosphate chemicals. A contract with one of these companies calls for establishment of by-product uranium recovery facilities, and other companies are setting up and operating pilot plants to further the process studies.

New York Gives Science Teachers Isotopes Course

On February 27, for the first time in the United States, a course in the use of radioisotopes in the science classroom was inaugurated. Attending for in-service credit were a large number of the high-school science teachers of the City of New York.

Entitled "Radioisotopes—A New Aid to High School Science Teachers," the course is sponsored by New York's Board of Education with the cooperation of the United Atomic Energy Commission. It comprises 15 lecture-demonstrations and will continue until June 11. Classes are held at New York University.

At the first session, registrants heard Paul C. Aebersold, chief of the AEC Isotopes Division, give an introductory lecture on isotopes, their manufacture, and handling. The remaining lectures include such topics as the fundamentals of radioactivity, radiochemistry, the operation and use of radiation-detection devices, and applications of radioisotopes for the study of metabolic processes in humans and plant growth. In many cases, demonstrations are to be given using the radioisotope under discussion.

The lecturers include V. Lawrence Parsegian, E. B. Meservey, Evelyn Jetter, H. DiGiovanni, and John H. Harley, of the New York Operations Office of AEC; L. P. Miller and R. M. Weed, of the Boyce Thompson Institute for Plant Research; Jacob Sacks, of Brookhaven National Laboratory; William F. Newman, of the University of Rochester; and S. M. Seidlin, of Montefiore Hospital.

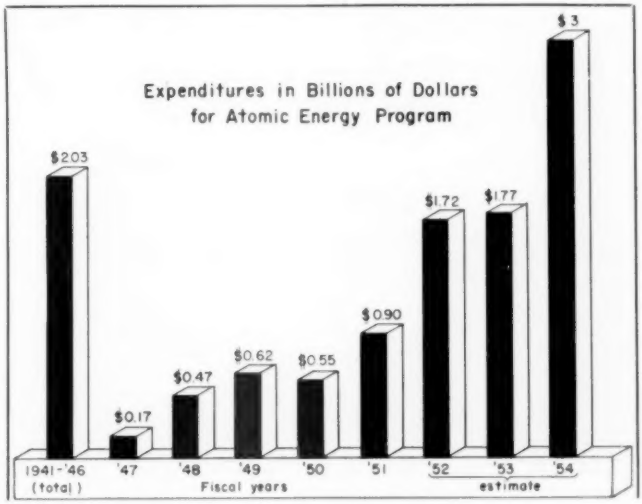
Dr. William Jansen, Superintendent of Schools in New York, has announced that as a result of this course, high schools in the city will begin using radioisotopes for demonstration purposes in science classes.

President Asks $1,755-Million for AEC for 1953, Announces Plans for $5- to $6-Billion Expansion

President Truman asked Congress in his recent budget message to authorize $1,775,000,000 for the "development and control of atomic energy" in the 1953 fiscal year, which begins next July 1, and recommended new obligational authority in the amount of $1,255,000,000 for the same period. Estimated expenditures for the 1952 fiscal year are expected to reach $1,725,000.

At the same time, the President announced plans for another major expansion of the program and facilities, beginning July 1, 1953. This, the third and largest expansion since the war, calls for the expenditure of $5,000,000,000 to $6,000,000,000 over a period of five years and, if completed in 1958 as proposed, will have more than quadrupled the nation's present capital investment in atomic energy. The graph on this page shows the effect of the expansion in view of total expenditures for the development of atomic energy since 1941.

The Atomic Energy Commission and the Department of Defense will present the new program to Congress



Actual expenditures (1941–51) and estimated expenditures (1952–54) in billions of dollars for the United States atomic-energy program. The amount shown for fiscal year 1954 is estimate that includes $1-billion in accordance with newly proposed $5- to $6-billion expansion over five-year period beginning July 1, 1953

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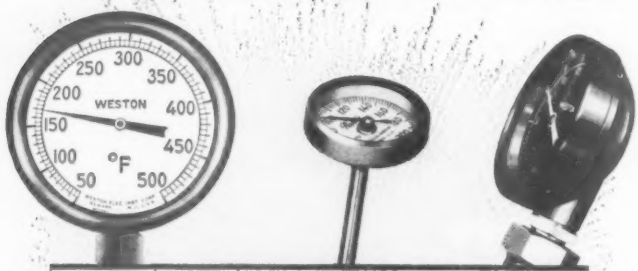

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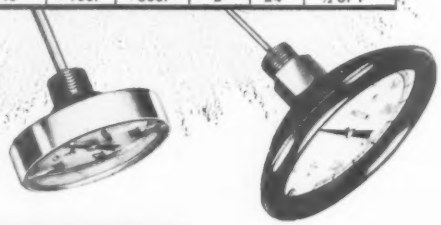

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shortly. The funds were not budgeted in the President's message because it was felt that this program would not appreciably affect expenditures before the end of the 1953 fiscal year. They would be funds over and above those needed for operation of the facilities and program existing at the end of the 1953 fiscal year.

The study for the expansion program was made in response to a resolution by the Joint Congressional Committee on Atomic Energy drawn up last fall. At that time, Senator Brien McMahon, the committee chairman, asked in a speech for an annual expenditure for the program of $6,000,000,000. While the President's expansion plan is tremendous, it involves nowhere near as much money as the McMahon plan.

Budget Provisions

Although pointing to progress in the industrial and other peacetime applications of atomic energy, the President said in his message that the principal emphasis of the atomic-energy program "continues to be placed on the national security."

Military expenditures proposed in the budget included funds for the Navy for construction of a second atomic-powered submarine.

AEC Negotiating Further Fission-Product Studies

Looking into possible future industrial uses for fission products, the Atomic Energy Commission recently reported the progress it is making toward getting basic technical information on the problem. According to the Commission statement, special kilocurie cobalt-60 sources are being used until specifications for fission-product sources and methods of preparing them are developed.

Brookhaven National Laboratory has furnished a 1-kilocurie Co^{60} source to the University of Michigan and Columbia University and a 1.5-kilocurie source to Massachusetts Institute of Technology. Stanford Research Institute is to be supplied with a 5-kilocurie and General Electric's General Engineering Laboratory with a 1.5-kilocurie source.

Besides the fundamental investigations being financed by the AEC, programs supported by private funds are being formulated. Sixteen firms, representing the antibiotics industry, are planning privately financed experi-

mentation using a 5- to 10-kilocurie source, and the AEC is completing negotiations with the Schering Corp., manufacturer of pharmaceuticals in Bloomfield, N. J., for that firm to finance its own program to determine the feasibility of sterilizing its products with radiation from fission products.

ORINS Schedules More Radioisotope Courses

Oak Ridge Institute of Nuclear Studies will give three additional courses in the techniques of using radioisotopes in research. Dates for the courses, scheduled for this summer, are June 9 to July 4; July 7 to August 1; and August 11 to Sept. 5.

Application blanks and additional information may be obtained from Ralph T. Overman, Chairman, Special Training Division, Oak Ridge Institute of Nuclear Studies, Oak Ridge, Tenn.

U. S. and Canada Exchange Data under New Law

The Atomic Energy Commission has announced that, in January, the United States exchanged atomic information with Canada—the exchange being the first made with any foreign country under the terms of the amendment to the Atomic Energy Act passed by Congress in October, 1951. AEC chairman Gordon Dean declined to define the nature of the exchange except to say that the data are "classified," that they concern a specific area of activity, and that "by the necessities of the case" the exchange "has to continue for a period."

Radiation Research Society Announces First Meeting

The organization of a new professional group to be known as the Radiation Research Society was recently announced by G. Failla of Columbia University. It will hold its first formal meeting on April 15 at 7:30 p.m. in New York at the Hotel Statler.

The Society will have three aims: (1) to promote original research in the natural sciences relating to radiation, (2) to facilitate integration of different disciplines in the study of radiation effects, and (3) to promote the diffusion of knowledge in those fields.

The meeting, to which charter members have been invited, will include

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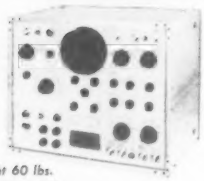

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a business session and two invited talks, one on *Radiation-induced Cataracts*, by Ludwig von Sallman of Columbia University, and the other on *Photoreactivation*, by Albert Kelner of Brandeis University. It is taking place in conjunction with the annual meeting in New York of the Federation of American Societies for Experimental Biology, April 14-18. Four of the Federation sessions and two symposia will be devoted to discussions of the effects of radiation.

Further information on the society can be obtained by writing to Dr. A. Edelmann, Biology Department, Brookhaven National Laboratory, Upton, New York.

AEC Sets Up Committee on Reactor Location Problems

A committee to assist with the nontechnical aspects of choosing new reactor sites has been organized by the Atomic Energy Commission. To be known as the Industrial Committee on Reactor Location Problems, it recently held its first meeting and is now on a tour of all AEC sites. C. Rogers McCullough of the Monsanto Chemical Co., St. Louis, Mo., has been named chairman.

The purpose of the committee is to assist and advise the AEC in determining the criteria to be used in the location of atomic-energy plants with regard to populated areas.

The other members of the committee are W. P. Conner, Jr., Hercules Powder Co., Wilmington, Del.; R. L. Doan, Phillips Petroleum Co., Idaho Falls, Idaho; K. R. Osborn, Allied Chemical and Dye Corp., New York, N. Y.; D. A. Rogers, Allied Chemical & Dye Corp., Morristown, Pa.; and Reuel C. Stratton, The Travelers Insurance Co., Hartford, Conn.

Michigan State College Plans Nuclear Conference

A two-day conference on "Atomic Energy and the Future" will be held at Michigan State College, East Lansing, Mich., on May 20 and 21. The course has been planned to interest chemical, manufacturing, and power industry representatives, engineering and science faculties in colleges and high schools, executives from industry, technicians, and public-health and civil-defense personnel.

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from the Argonne National Laboratory, the AEC Reactor Division, the Detroit Edison and Dow Chemical companies have been obtained for the course. The program and registration fee will be announced shortly.

Further information can be obtained from the conference program chairman, Professor Donald J. Renwick, Mechanical Engineering Department, Michigan State College, East Lansing, Michigan.

North American Philips to Give Diffraction Course

North American Philips Company, Inc., will hold its twelfth X-ray Diffraction School at the company's plant, 750 South Fulton Avenue, Mount Vernon, N. Y., from April 21–25. Guest scientists and educators will cover such subjects as fluorescence analysis, Geiger-counter X-ray spectrometry, electron microscopy, X-ray and electron diffraction, and new high- and low-temperature camera techniques. Sessions involve extensive classroom and laboratory work.

Over $250,000 Paid in AEC Ore Bonuses in 1951

Last year, under the new graduated bonus arrangement, the Atomic Energy Commission paid out more than a quarter million dollars to uranium-ore producers.

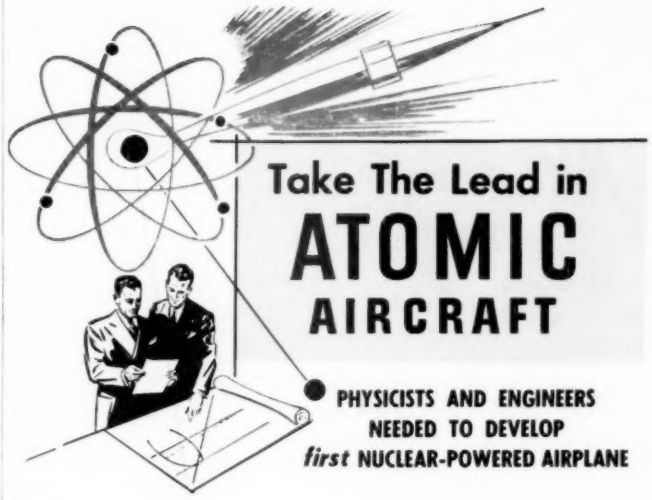
The incentive bonuses, which are based on the uranium oxide content of the ore, have resulted in a sizable increase in the income of many small mining operators and have stepped up output of this raw material for the atomic-energy program.

IN BRIEF

• *During the last six months of 1951, 3% of the nation's total building expenditure went to the expansion of atomic-energy facilities, with nearly 2% of the nation's construction force employed on AEC jobs.*

• The Hydro Electric Commission of Ontario is holding high-level discussions with Chalk River scientists to see if partnership can speed up the day of economic production of power from atomic energy.

• *In its spring semester, Columbia University is offering for the first time a*



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PHYSICISTS AND ENGINEERS NEEDED TO DEVELOP *first* NUCLEAR-POWERED AIRPLANE

A CHALLENGE TO YOU

Convair awarded U. S. Air Force contract to develop the airframe for the first Nuclear-powered airplane. Opportunities available in:

NUCLEAR PHYSICS	AERODYNAMICS	SERVO MECHANISMS
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ANALYTICAL and PHYSICAL CHEMISTRY	DYNAMICS	WEIGHTS CONTROL
EQUIPMENT DESIGN	AEROPHYSICS	ELECTRICAL, MECHANICAL and STRUCTURAL TESTING
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EXCELLENT WORKING CONDITIONS

Travel and moving allowance for those who qualify—group insurance including hospitalization for employees and families—retirement plan—recreational activities for employees and families—modern air-conditioned plant—opportunity for "in plant" graduate and undergraduate study—desirable work schedule.

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A city for family life—50 parks—lakes—excellent schools—big time baseball, football, basketball, golf, rodeo—ice arena—opera and concerts—good year round climate—no smoke—Western Hospitality.

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Complete 1-, 2-, or 4-channel systems *ready for use*, or as separate instruments (Amplifiers, Preamplifiers, and Recorders).

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Permanent records produced with heated stylus on continuous, plastic coated chart paper.

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course in Radiologic Physics. It will be presented under the direction of Edith Quimby and include instruction on radiation measurement, protection against radiation, and the use of radioisotopes.

• An assembly and test building for reactor components is going to be built at the Knolls Atomic Power Laboratory, which is operated for the AEC by the General Electric Company in Schenectady, N. Y. Ardini & Pfau, Inc., of Syracuse, N. Y., has been awarded a $373,000 contract by AEC for the construction work.

• *Nine thousand lots of radioisotopes were produced at Harwell in 1951, according to a recent announcement of the Ministry of Supply. This is 50% more than in 1950. Great Britain's exports of radioisotopes have increased tremendously as a result of the higher production.*

• A course for physicists and engineers who want to know more about electronic instruments in nuclear physics is being given at the Atomic Energy Establishment at Harwell, England, starting on May 19.

NUCLEAR NEWSMAKERS

Arthur C. Lankford has joined AEC's Idaho Operations Office as chief of the organization and methods branch of the division of organization and personnel. He formerly held a similar position with the U. S. Bureau of Reclamation in Salt Lake City.

Brewer F. Boardman, with the AEC's Technical Information division in Oak Ridge, Tenn., since 1947, has taken up a new appointment as chief of the technical information branch of the AEC's Idaho Operations Office.

John R. Huffman, formerly of Argonne National Laboratory, has joined the atomic energy division of Phillips Petroleum Co. at Idaho Falls, Idaho, as a senior engineer.

Robert D. Fowler has been appointed associate leader in the division of chemistry and metallurgy, Los Alamos Scientific Laboratory. He came to Los Alamos from Johns Hopkins University.

Maj. Gen. Thomas F. Farrell, who became assistant general manager of the Atomic Energy Commission last August, has resigned the post to become managing director of Aro, Inc., the company that will operate the Air

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THE THEORY OF ISOTOPE SEPARATION

As applied to the Large-Scale Production of U^{235}

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1. **Explains the theories of cascade separation . . . and describes specific separation methods in which the theories are applied.** *The first connected account of cascade separation theories to be published,* this book brings you results of vast research on isotopes carried out on the Manhattan Project. Theories are applicable to separation by diffusion, exchange reactions, thermal diffusion, exchange reaction, electrolysis.

By Carl Cohen, Dir., Atomic Energy Div., H. K. Ferguson Co. Edited by George M. Murphy. Div. III, Vol. 1 B, National Nuclear Energy Series. 165 pp., 40 illus., $2.00

PHYSICAL PROPERTIES AND ANALYSIS OF HEAVY WATER

Just Published!

2. **Discusses the physical properties of heavy water, the equilibrium constants for exchange reactions.** Covers isotope analysis by mass spectrometer, with many refinements for very precise work and successful application to isotope analysis of heavy water.

By Isidor Kirshenbaum, Esso Laboratories, Edited by Harold C. Urey, Univ. of Chicago, and George M. Murphy, N.Y.U. Div. III, Vol. 4 A, National Nuclear Energy Series. 438 pp., 149 illus., $5.25

FUNDAMENTALS OF ATOMIC PHYSICS

3. **A thorough reference on atomic and nuclear fundamentals in the simplest possible terms.** Covers high-voltage particle accelerators, the kinetic theory of gases, charge and mass of electron, electronics, photoelectric effects, X-rays, the Bohr theory of the origin of spectral lines, electron configuration in atoms. Treats matter waves, isotopes, and other important factors. **By Saul Dushman, Research Consulant, Gen. Elec. Co., Schenectady. 294 pages, 68 Illus. $5.50**

The Organization of INDUSTRIAL SCIENTIFIC RESEARCH

4. **A thorough analysis of the methods actually used for the organization and operation** of industrial research laboratories. Gives detailed information on the selection of the laboratory program—the direction of research—the financial administration of the laboratory—and a number of auxiliary services. **By C. E. Kenneth Mees and John A. Leermakers, both of the Research Department, Eastman Kodak Company. 383 pp., illus., $6.00**

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This offer applies to U. S. only

Force's new engineering test center under construction at Tullahoma, Tennessee.

Walter E. Kingston has been appointed director of the new atomic energy division of Sylvania Electric Products, Inc. With the company since 1931 and more recently head of Sylvania's metallurgical laboratories, he will direct an expanded program of research and development in the field of nuclear reactor materials.

James De Juren, formerly associated with the University of California Radiation Laboratory, has joined the atomic and radiation physics division of the National Bureau of Standards.

MEETINGS

The Physical Society, 36th Annual Exhibition of Scientific Instruments and Apparatus—Royal College of Science, London, England, Apr. 3–8

Symposium on Radiation Chemistry, sponsored by the Faraday Society—University at Leeds, England, Apr. 8–10

American Physical Society, Southeastern Section—North Carolina State College, Raleigh, N. C., Apr. 10–12

American Society of Biological Chemists, Annual Meeting—Hotel New Yorker, New York, N. Y., Apr. 14–18

Federation of American Societies for Experimental Biology, 36th Annual Meeting—Hotel Statler, Hotel New Yorker, New York, N. Y., Apr. 14–18

American Physical Society, Spring Meeting of New York Section—Corning, N. Y., Apr. 18–19

American Society of Mechanical Engineers, Nuclear Energy Division of Metropolitan Section (meeting on "Engineering Applications of Radioactive Isotopes")—New York, Apr. 22

American Industrial Hygiene Association—Netherland Plaza Hotel, Cincinnati, Ohio, Apr. 22–24

Sixth Annual Symposium on Fundamental Cancer Research; also Cancer Pathology and Radiology Conference on Tumors and Other Diseases of Bone (sponsored by University of Texas and College of American Pathologists—Shamrock Hotel, Houston, Texas, Apr. 25–26

National Academy of Sciences, Annual Meeting—Washington, D. C., Apr. 28–30

1952 Metal Powder Show, Metal Powder Association, 8th Annual Meeting—Drake Hotel, Chicago, Ill., Apr. 29–30

American Physical Society—Washington, D. C., May 1–3

The Electrochemical Society, 50th Anniversary Meeting, including Symposium on Rare Metals—Philadelphia, Pa., May 4–8

Scientific Apparatus Makers Association, Annual Meeting—Edgewater Beach Hotel, Chicago, Ill., May 6–9

25th International Congress for Industrial Chemistry—Frankfort am Main, Germany, May 18–25

American Society of X-Ray Technicians, Annual Meeting—Morrison Hotel, Chicago, Ill., May 25–29

GLOW TRANSFER COUNTERS

The Ericsson Tube
Manufactured by
Etelco Ltd., London, England

NOW DISTRIBUTED
EXCLUSIVELY IN AMERICA BY

ATOMIC
INSTRUMENT COMPANY

The Decade Counter Tube (Model GC10A) is a cold cathode gas filled multi-element tube in which decade counting is achieved by the transfer of ionization from element to element within a single envelope. The GC10A will reliably handle up to 400 cycles or pulses per second — other tubes will later be available for operation up to higher cycles per second.

Glow transfer decades may be cascaded with only one double triode required to drive each stage. Addition of a simple switch to each stage will permit subtraction as well as addition. Resetting is entirely electronic — several units can be reset to zero with a single pair of switch contracts.

High speed and lack of moving parts make Glow Transfer Decades ideal for totalizers or where noisy mechanical devices would be prohibited.

Tubes are available in several counter assemblies or for incorporation in original equipment. For complete details, write today for Bulletin N-3. Ask also for Atomic's new *Fast Register* based on these tubes.

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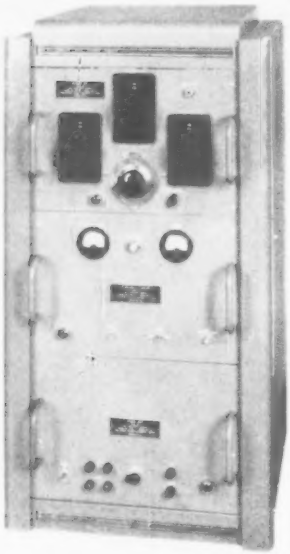
PRODUCTS AND MATERIALS

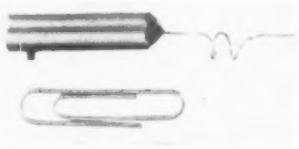


Frequency Marker

Polarad Electronics Corp., 100 Metropolitan Ave., Brooklyn 11, N. Y. This frequency marker produces calibration signals at precisely determined intervals of 1 Mc in the frequency range 950–2,040 Mc. Particular markers can be selected, and all others rejected. It is claimed that the frequency determination is accurate to one part in 10^6. An interpolation oscillator produces a comparison signal by which an unknown frequency can be determined to within ±10 kc.

Low-Voltage Supply

Kepco Laboratories, Inc., 149-14 41st Ave., Flushing 55, N. Y. The d-c output voltage of the model 3100 power supply is continuously variable in the range 0–3 volts; currents in the range 0–100 ma can be delivered. Output voltage variation is said to be 5 mv for line fluctuations from 105 to 125 volts, and over the full range of load variation. Ripple is 1 mv, it is claimed.



Miniature Thermostat

Thomas A. Edison, Inc., Instrument Division, 29 Lakeside Ave., West Orange, N. J. This adjustable thermostat is metal-enclosed. It has a temperature range from −50° to 350° F, and is adjustable ±60° F from its factory setting. Contacts are rated at 1 ampere, 115 volts, a-c, or 0.5 ampere, 115 volts, d-c. Over-all length is 1¼ in., and diameter is about 5/16 in.

Storage Cabinet

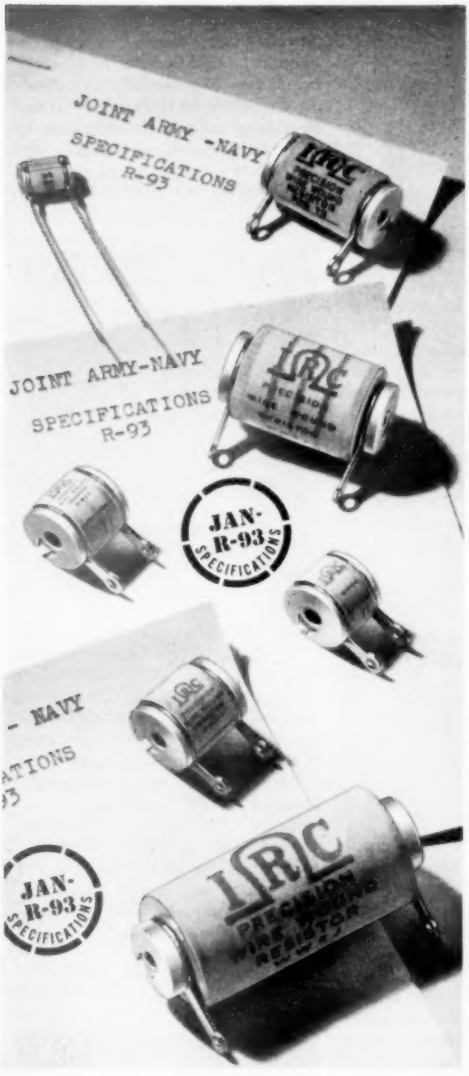
Nuclear Instrument and Chemical Corp., 229 W. Erie St., Chicago, Ill. The model N4 cabinet is designed for storage of radioactive samples. Provision has been made for replacing sample holders or the sample holding tray in case of contamination. Sample holders are plastic cups which are pressed into holes in the tray. The cabinet is provided with 10 drawers, each provided with 10 sample holders. Also provided is a dust-tight cover which may be placed over the cabinet for protection against contamination of samples.

Surface Monitor

Radioactive Products, Inc., 443 W. Congress St., Detroit 26, Mich. This alpha-survey meter, model D-3, is calibrated 0–500, 0–2,500, and 0–12,500 cpm. Background is 2 cpm, it is claimed. A 2-Mev alpha will penetrate the window, which is 3/16 in. above the flat surface. An ionization chamber in the bottom is used for table-top monitoring; a connector provides for an external probe containing chamber and preamplifier for checking irregular surfaces. Response time of the instrument is between 5 and 8 sec. Drift over an 8-hr period is said to be 10% of full scale.

Scintillation Counter

Nuclear Research Corp., 2563 Grays Ferry Ave., Philadelphia 46, Pa. The model SC-1A scintillation-counter probe includes a permanent thallium-activated sodium iodide crystal mounted in a removable Lucite cap, a 5819 photomultiplier with necessary circuitry, and a 6-ft cable and connector. A variety of Lucite caps is available for use with different types of



UNBIASED TESTS PROVE THESE NEW PRECISION WIRE WOUNDS

MOST RELIABLE AND STABLE OF ALL!

This is no flight of fancy. Tested side-by-side with competing resistors, on the most modern testing equipment, IRC's new Type WW Precision Wire Wounds proved vastly superior in reliability and stability!

Actually, new Type WW's *far surpass JAN-R-93 characteristic B Specifications.* Severe cycling and 100-hour load tests resulted in virtually zero changes in resistance. Other stringent tests proved Type WW's high mechanical strength, freedom from shorting, resistance to high humidity.

	Original Resist.	1st Cycle % Chge	2nd Cycle % Chge	3rd Cycle % Chge	4th Cycle % Chge	Resist. at End of 100 hrs. load	Total % Chge	% Chge from Last Temp. Cycle to End of 100 hrs. load %	Resistance Chge at End of 100 Hrs. Load only % (no cycling)
1	100,010	+ .04	+ .04	+ .05	+ .05	100,050	+ .04	— .01	100,040 — .02
2	100,000	+ .03	+ .04	+ .03	+ .05	100,060	+ .06	+ .01	100,000 0
3	100,000	+ .01	+ .02	+ .02	+ .05	100,000	0	+ .05	100,050 — .02
4	100,000	+ .02	0	+ .02	+ .02	100,000	0	— .02	100,040 — .01
5	100,010	+ .03	+ .04	+ .04	+ .05	100,000	0	— .05	100,030 — .03
6	100,000	0	+ .03	+ .04	+ .04	100,100	+ .1	+ .06	99,980 0
7	100,000	+ .04	+ .05	+ .04	+ .04	100,070	+ .07	+ .03	100,000 0
8	100,000	+ .03	+ .05	+ .05	+ .05	100,050	+ .05	0	100,000 0
9	100,000	+ .04	+ .03	+ .05	+ .04	100,010	+ .01	— .03	100,050 0
10	100,000	+ .02	+ .02	+ .02	+ .04	100,010	+ .01	— .03	100,000 0
11	100,000	0	+ .01	+ .01	+ .03	100,000	0	— .03	

NEW WINDING FORMS hold more wire, giving higher resistance values. Non-hygroscopic ceramic assures high insulation qualities, high mechanical strength and low coefficient of thermal expansion.

NEW WINDING TECHNIQUE eliminates possibility of shorted turns or winding strains. All wire used in construction is given rigid insulation tests of special enamel coating, and special attention is given to insure transfer of wire to winding form without strain or break in insulation.

NEW TYPE INSULATION withstands humidity, assures long life. Winding is multiple vacuum impregnated with new IRC-developed compound which retains same consistency throughout entire range of temperatures to which resistors are exposed. Neither glassy hard nor tacky soft under any condition, this prevents wire strains, provides stability and freedom from noise.

NEW TERMINATIONS are rugged lug terminals for solder connection. These provide dependable and strain-free winding terminations. Only WW-10, because of small size, is provided with wire lead termination 2" long.

Send for full technical data on these new Precision Wire Wounds—and be sure to ask about our Industrial Service Plan. It enables your IRC Distributor to give you 'round-the-corner delivery of experimental or pilot-run quantities—right from local stocks.

Wherever the Circuit Says ~~~

Power Resistors • Voltmeter Multipliers
Insulated Composition Resistors
Low Wattage Wire Wounds
Controls • Voltage Dividers
Deposited Carbon Precisions
HF and High Voltage Resistors
Precisions • Insulated Chokes

IRC

INTERNATIONAL RESISTANCE COMPANY
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In Canada: International Resistance Co., Ltd., Toronto, Licensee.

INTERNATIONAL RESISTANCE COMPANY
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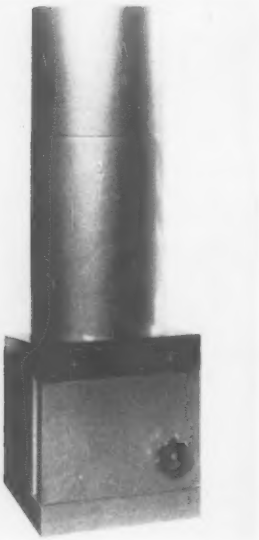
Please send me additional information on IRC Type WW Precision Wire Wound Resistors ( )—Name and address of local IRC Distributor ( ).

*Name*_____
*Title*_____
*Company*_____
*Address*_____
*City*_____ *State*_____

radiation and for different physical applications. Starting potential of the counter is 900 ± 100 volts; operating potential is 1,000 ± 100 volts. Efficiency with Co^{60} is said to be 30%. The counter can be operated by plugging it into a conventional scaler or ratemeter. Also available is a lead collimator for use with the standard crystal cap.

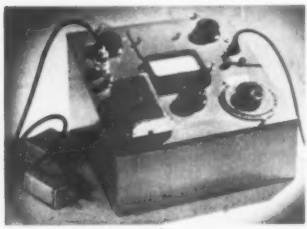


Scintillation Counter

E. K. Cole, Ltd., Southend-on-Sea, England. The N502 counter comprises an 11-stage photomultiplier, an interchangeable phosphor, and a sample holder, all contained in a lead castle 5 cm thick. A wide-band amplifier is mounted on the castle. A light-tight drawer at the base of the instrument houses crystal or liquid phosphors; a door gives access to the sample changer. Accurately positioned shelves are provided to hold sample and absorbers. The phototube, EMI type 5311, has an over-all gain of 10^7 at 160 volts per stage; effective area of the cathode is 5 cm^2. The amplifier has alternative gains of 30, 100, or 300; gain stability is 1%. Rise time of the amplifier varies from 0.25 to 0.5 μsec, depending on gain. Impedance of the output stage is about 150 ohms. Dynode voltages are provided by a stable potentiometer network; one stage of high-voltage filtering is provided.

Centrifuge

Scientific Glass Apparatus Co., Inc., Bloomfield, N. J. This angle-head centrifuge will hold four 15-ml standard metal shields. The 115-volt, a-c, 60-cycle motor draws 1.5 amperes and rotates at 1,550 rpm. All rotating parts of the device are concealed by an aluminum guard. The motor is secured to a cast-iron base, which sits on rubber feet, and is ventilated for continuous operation.

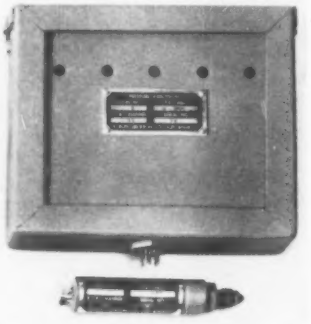


Electrometer

Special Instruments Laboratory, Inc., 1003 Highland Ave., Knoxville, Tenn. The model 145 electrometer is a-c operated, and will measure d-c potentials in the range 0–150 mv. Special modification to give full-scale deflection of 30 mv is available. Input terminals are available inside a shielded compartment on the front panel, or on a probe which may be used remotely. Input impedances of 10^9, 10^{10}, 10^{11}, or 10^{12} ohms may be selected. Provision is made for connection to a strip-chart recorder.

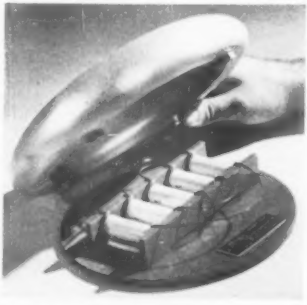
Oscilloscope

Television Equipment Corp., 238 William St., New York 38, N. Y. The model T-601B oscilloscope has a 5-in. screen. The Y-axis response is said to be within 3 db from 2 cycles to 12 megacycles at 10 mv, rms, per inch of deflection sensitivity. The sweep generator provides either recurrent sweeps from 10 cycles to 100 kilocycles, or triggered sweeps from 5μsec to 10^5 μsec. Phasing is provided for 60-cycle sweeps and all sweeps may be synchronized to either positive or negative peaks.



Pressure Gage

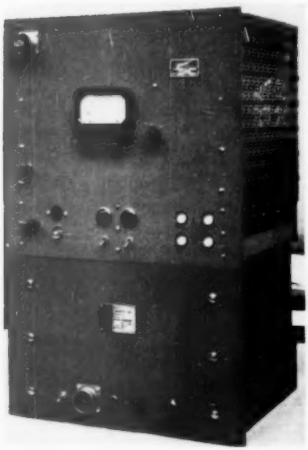
Byron Jackson Co., Oil Tool Division, P. O. Box 2017, Terminal Annex, Los Angeles 54, Calif. The model PM-14 pressure gage is available with pressure ranges of 0–3 psi to 0–5,000 psi, with a deviation from linearity of ±1% of maximum. Operating temperature range is −70° to 250° F; this can be extended to 400° F with special construction. The frequency of the model D-1 oscillator is remotely controlled by the pressure gage, and has an output of 10 volts, a-c, into a 50,000-ohm load. The minimum and maximum operating frequencies available are 1.5 kc and 12 kc, respectively.



High-Voltage Resistor

Astro Electric Co., 1302 County Rd., Belmont, Calif. The type 1001 re-

sistor gives voltage drops from 5 to 100 kv, with maximum current drain of 1 ma, for voltage measuring operations. Housed in a spun-aluminum corona shield, the unit contains five series-connected 1-megohm resistors, rated at a precision of 0.1% at 74° F. Up to 20 units can be stacked and series connected. Metering taps can be brought out at any point.



Voltage Regulator

Magnetics, Inc., 135 Bloomfield Ave., Bloomfield, N. J. This klystron d-c voltage regulator makes use of an all-magnetic amplifier-type circuit. It maintains power-supply output at 18,000 volts, d-c, for load current variations in the range 0–100 ma, and line voltage variations in the range 105–135 volts, a-c. Regulation accuracy is said to be ±1%; time delay is about 0.1 sec. The instrument may be easily modified for power supplies of any output rating.

Pressure Transmitter

Automatic Temperature Control Co., Inc., 5200 Pulaski Ave., Philadelphia 44, Pa. This device is designed to measure vacuum pressures with reference to an absolute pressure. It consists of two opposing bellows connected to a cantilever beam spring and a differential transformer. The transformer needs only 0.01 gm for displacement of its armature to give an a-c output signal linear to within 0.1%. Available in five standard ranges from 0–50 mm Hg to 0–30 in. Hg, the transmitters are calibrated to an accuracy of 0.50% of full range.

Volt-Ammeter

Pyramid Instrument Corp., Lynbrook, N. Y. This snap-around-type ammeter, model 1200, can measure alternating current in six ranges. The ranges have maximum readings of 15, 60, 150, 300, 600, and 1,200 amperes. For measuring voltage, there are three ranges with maximum readings of 150, 300, and 600 volts, a-c. The transformer design is said practically to eliminate error in current measurement due to position of the conductor within the jaws. Probe jaws are insulated down into the sockets, to eliminate danger of shorts. The meter case is dust proofed.

Scaler

Radiation Instrument Development Laboratory, 2337 W. 67th St., Chicago 36, Ill. The model 66 scale-of-32 G-M scaler has a pulse-height control variable from ½ to 10 volts. Electronic resolving time is said to be 5 μsec. A six-digit mechanical register is mounted on the front panel. An external clock can be synchronized with the count switch. The high-voltage is continuously variable in the range 500–2,500 volts; regulation is said to be 0.01% of line voltage change. The 4½-in. front-panel meter is calibrated to 2% of full scale.

Ceramics

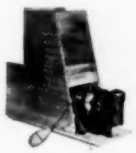
Stupakoff Ceramic and Manufacturing Co., Latrobe, Pa. These ceramic materials can be formed by pressing, extruding, casting, and ramming. They have very low coefficients of expansion, and are able to withstand

For Measuring RADIOACTIVE EMISSIONS

8.3 x 6.3 x 3. 5 cm. Weight 0.17 kg.

LINDEMANN-RYERSON ELECTROMETER

Was first used for photo-electric measurements. Is now used in conjunction with ionization chambers for the determination of radioactive emission. Compact, sturdy, high sensitivity, stable zero and requires no leveling. Capacitance is about 3 cm. Includes improvements developed by the Ryerson Laboratory.



PORTABLE Projection Viewer for Lindemann-Ryerson Electrometer.

POCKET GAMMA RAY DOSIMETER

is a personnel monitoring instrument to measure cumulative exposure to gamma or x-rays over a given period. Contains an ionization chamber, a quartz fiber electrometer and viewing system.

"CHANG and ENG" FAST NEUTRON DETECTOR

follows closely original design of U. S. Atomic Energy Commission. Consists of twin ionization chambers, Lindemann Electrometer, reading microscope and dry cells. Self contained.

PRECISION IONIZATION METER (Failla Design)

A complete instrument for null methods of radioactivity measurements where background radiation effects must be eliminated.

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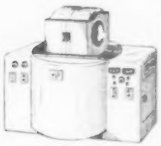
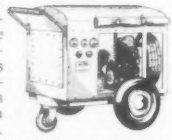
Low Pressure Helium Liquefier. Produces 4 liters liquid helium per hour. Maintains temperatures down to 271°C. Liquefies other gases, such as O_2, H_2, N_2. Available as proven equipment.



ADL Electromagnet

Compact, Multipurpose Research Electromagnet. Weighs only 2 tons. Produces field strength up to 40,000 gauss with 20 KW. Provides variety of field patterns — interchangeable pole pieces. Available as proven equipment.

Self-contained, Gaseous Helium Cycle Refrigerator. To prevent evaporation loss from tanks containing liquefied gases such as liquid oxygen and liquid hydrogen.



ADL Helium Refrigerator

ADL Hydrogen Liquefier

A safe, convenient method for liquefying hydrogen or practically any other gas. Based on the proven, low-pressure, gaseous helium refrigerating cycle used so successfully in our ADL Collins Helium Cryostat.

These are but a few examples of Arthur D. Little Mechanical Division's services in developing specific items from the idea through the complete manufactured unit.

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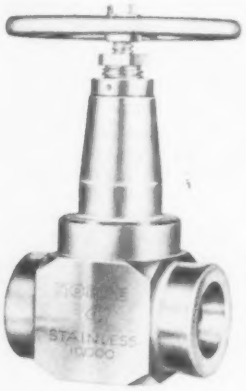
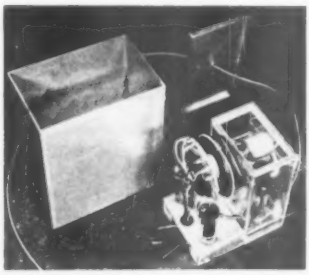
severe thermal shock. The material can be used at temperatures up to 2,400° F. By machining or grinding after firing, the dimensions can be held to close tolerances.



Valve

A. F. Hoppe Engineering Inc., Greensboro, Ind. This stainless-steel valve is forged, and parts are machined and welded together. Size and weight have been reduced 75–85% compared to cast-steel valves. Packing-gland bolts have been eliminated. Internal parts are polished to help prevent corrosion. Valves can be obtained in the range ½–6 in., horizontal or angle. Check valves are of the piston type.



Power Supply

North American Philips Co., Inc., 750 S. Fulton Ave., Mt. Vernon, N. Y. This regulated high-voltage supply is for use with cathode-ray and G-M tubes. Input is 315 volts, d-c, 50 ma; output is 18 kv, d-c, 150 μa. Lower voltages may be taken off. Ripple is

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1%. The unit operates at temperatures from −30° to +80° C. The instrument can be furnished with different voltage and current ratings.

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LITERATURE AVAILABLE

Transformers. Catalog GEA-4626E gives all data on indoor and outdoor transformers. *General Electric Co., Schenectady 5, N. Y.*

Relays. Catalog illustrates line of relays. *Advance Electric and Relay Co., 2435 N. Naomi St., Burbank, Calif.*

Jet pumps. Bulletin 512 gives technical data on line of pumps. *Penberthy Injector Co., 1242 Holden Ave., Detroit 2, Mich.*

Metals. Bulletin BC-51 describes properties of braze-clad metals. *American Silver Co., Inc., Rolled Plate Division, 36-07 Prince St., Flushing, N. Y.*

Instruments. Bulletin 1150 shows radiation detection and measurement instruments. *El-Tronics, Inc., 2647 N. Howard St., Philadelphia, Pa.*

Servoamplifiers. Data sheets give properties of servo amplifiers. *Servomechanisms, Inc., Post and Stewart Aves., Westbury, N. Y.*

Valves. Catalog illustrates relief valves for original equipment application. *Kunkle Valve Co., 101 S. Clinton St., Fort Wayne, Ind.*

Demineralizer. Bulletin 124 describes water-treatment device for laboratories. *Barnstead Still & Sterilizer Co., 2 Lanesville Terrace, Boston 31, Mass.*

X-ray diffraction. Booklet explains uses of X-ray diffraction equipment. *North American Philips Co., Inc., 750 S. Fulton Ave., Mt. Vernon, N. Y.*

Resistors. Data sheet 155 gives characteristics of variable resistors. *Chicago Telephone Supply Corp., Elkhart, Ind.*

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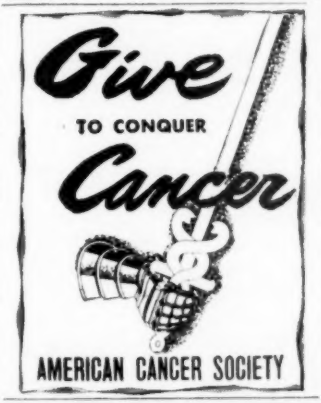

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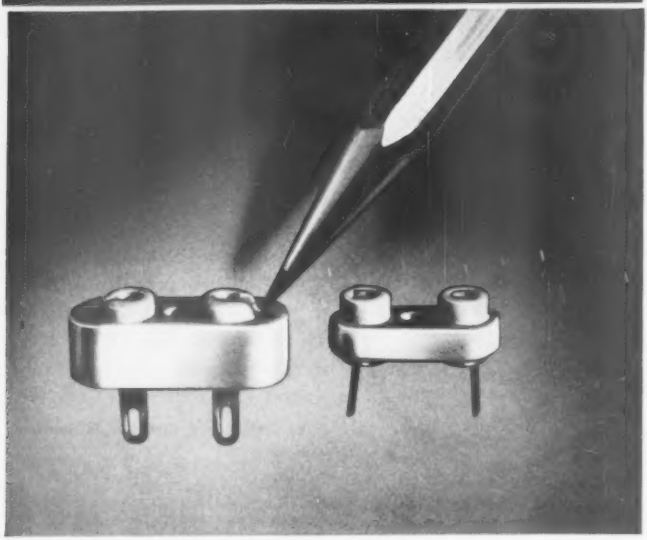

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OAK RIDGE A1 LINEAR AMPLIFIER—RCL MARK 15 MODEL A1

The Oak Ridge National Laboratory has developed and widely used an excellent and versatile linear amplifier suitable for pulse work. This instrument, for the first time, exactly to Oak Ridge specification, is now commercially available from Radiation Counter Laboratories, Inc. The price of the Oak Ridge A1 Linear Amplifier is $520.00. The Model A1A Linear Preamplifier is also available and must be used with the A1 Linear Amplifier when making nuclear measurements. The price is $125.00.

SPECIFICATIONS

Gain: Maximum gain 1,700, variable down to 1.5% of maximum by fine and coarse controls. Fine gain control adjusts signal between 50 and 100%. Coarse gain control adjusts signal in six steps, each step exactly a factor of 2, approximately equal in magnitude to the variation in signal available by adjustment of the fine gain control.

Response: Bandwidths of 2 mc., 0.5 mc., and 0.1 mc. are obtainable by front panel switch. Rise time of 0.2 microseconds. Delay time—0.45 microseconds with 2 mc. bandwidth.

Pulse Height Discriminator: Variable from 0 to 100 volts by large four-inch dial. Voltage is read directly from dial. Accuracy ±0.5 volts.

Linearity: No departure from linearity greater than 2%.

Outputs: The output of the main amplifier is available at "High" and "Low" output jacks, related by a factor of approximately 20. The output of the Pulse Height Discriminator is positive and has an amplitude of 3 volts and a duration of 0.4 microseconds. This may be used for driving a scalar or triggering a scope by means of a coaxial cable. All three connectors are Amphenol 83-1RTY.

Power Supply: Designed to operate from a 115 volt, 60 cycle A.C. line. An electronically regulated power supply is included.

Cabinet: Finished in copper-plated smooth grey hammertone. All hardware is stainless steel where possible.

Accessories: The RCL Mark 15 Model A1A Linear Preamplifier is available and is designed to be used with the Oak Ridge A1 Linear Amplifier. It consists of a three stage feedback amplifier followed by a cathode follower, and has a gain of approximately 30. The cathode-follower cathode resistor is the imput resistor in the A1 Amplifier. This Preamplifier serves the purpose of matching the impedances between the counter and the A1 Linear Amplifier.

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"NEUT" for Measurement of Fast Neutrons

NUCLEAR Model 2714 "Neut" ion chamber type survey meter is used for health monitoring near reactors . . . measuring fast neutron flux in a gamma ray field. It, too, is the only commercially manufactured instrument of its type.

Four ranges of gamma and neutron radiation rates are provided. Interchangeable ion chambers allow measurement of gamma-plus-neutron flux and gamma flux only, thereby permitting determination of neutron radiation.

TECHNOLOGISTS in the field of atomic reactor construction and operation can look to NUCLEAR for expert advice, assistance and equipment in all phases of reactor instrumentation and control. NUCLEAR has a background of experience in this field, represented in part by scientists who participated actively in the instrumentation of the early reactors, and by a continuous research and development program which has evolved a number of commercially manufactured instruments, of which the thermopile and "Neut" are representative examples.

In addition to instruments for atomic reactors, NUCLEAR'S complete matched line of survey, counting, and analysis instruments for use with reactor products enables pile operators to secure proven precision instruments for every need from a single source. A variety of radioactive chemicals is also marketed by NUCLEAR.

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